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VOLUME XLIX NUMBER 1

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

EDITED BY

GEORGE E. HALE
Mount Wilson Solar Observatory of the Carnegie Institution of Washington

EDWIN B. FROST
Yerkes Observatory of the University of Chicago

HENRY G. GALE
Major, U.S.A. in France

JANUARY 1919

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THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS, U.S.A.

THE CAMBRIDGE UNIVERSITY PRESS, London and Edinburgh
THE MARUZEN-KABUSHIKI-KAISHA, Tokyo, Osaka, Kyoto, Fukuoka, Sendai
THE MISSION BOOK COMPANY, Shanghai

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The Astrophysical Journal is published by the University of Chicago at the University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois, during each month except February and August. ¶The subscription price is $5.00 a year; the price of single copies is 65 cents. Orders for service of less than a half-year will be charged at the single-copy rate. ¶Postage is prepaid by the publishers on all orders from the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands, Shanghai. ¶Postage is charged extra as follows: For Canada, 30 cents on annual subscriptions (total $5.30), on single copies, 3 cents (total 68 cents); for all other countries in the Postal Union, 62 cents on annual subscriptions (total $5.62), on single copies, 11 cents (total 76 cents). ¶Patrons are requested to make all remittances payable to The University of Chicago Press in postal or express money orders or bank drafts.

The following are authorized to quote the prices indicated:

For the British Empire: The Cambridge University Press, Fetter Lane, London, E.C. 4. Yearly subscriptions, including postage, 23*s.* each; single copies, including postage, 3*s.* 3*d.* each.

For Japan and Korea: The Maruzen-Kabushiki-Kaisha, 11 to 16 Nihonbashi Tori Sanchome, Tokyo, Japan. Yearly subscriptions, including postage, Yen 11.25 each; single copies, including postage, Yen 1.50 each.

For China: The Mission Book Company, 18 Peking Road, Shanghai. Yearly subscriptions, $5.00; single copies, 65 cents, or their equivalents in Chinese money. Postage extra, if mailed direct outside of Shanghai, on yearly subscriptions 62 cents, on single copies 11 cents.

Claims for missing numbers should be made within the month following the regular month of publication. The publishers expect to supply missing numbers free only when losses have been sustained in transit, and when the reserve stock will permit. Deliveries are not guaranteed in the war zones of Europe, nor in other countries where transportation is disturbed by conditions incident to war.

Business correspondence should be addressed to The University of Chicago Press, Chicago, Illinois.

Communications for the editors and manuscripts should be addressed to the Editors of THE ASTROPHYSICAL JOURNAL, Yerkes Observatory, Williams Bay, Wisconsin.

The cable address of the Editorial Office is "Arcturus, Chicago."

The articles in this Journal are indexed in the *Readers' Guide Supplement*, New York, N.Y.

Entered as second-class matter, January 17, 1895, at the Post-office at Chicago, Ill., under the act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorised on July 13, 1918.

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VOLUME XLIX JANUARY 1919 NUMBER 1

ON THE DARK MARKINGS OF THE SKY
WITH A CATALOGUE OF 182 SUCH OBJECTS

By E. E. BARNARD

It would be unwise to assume that all the dark places shown on photographs of the sky are due to intervening opaque masses between us and the stars. In a considerable number of cases no other explanation seems possible, but some of them are doubtless only vacancies.

I do not think it necessary to urge the fact that there are obscuring masses of matter in space. This has been quite definitely proved in my former papers on this subject. If any doubt remains of this it will perhaps be readily dispelled by a close examination of the photographs previously printed. The conclusive ones I think are:

1. The photograph of the nebula about Nu Scorpii[1] which clearly shows partial and complete obscuration by the great wing-like nebula that covers much of the immediate region of Nu Scorpii and extends southward to the great nebula of Rho Ophiuchi.

2. The region of Rho Ophiuchi, where a large space of sky is blotted out by a great and beautiful nebula.[2] The fact of obscuration is clearly evident here, for wherever a trace of the nebula

[1] *Astrophysical Journal*, 31, 1910, Plate I, facing p. 8.

[2] *Ibid.*, Plate II*a*, facing p. 10.

extends, especially to the west, the general background of small stars is sharply blotted out.

3. Especially conclusive is the object (No. 7) which is shown in an article in this *Journal*[1] on a nebulous background in Taurus, where a nebula, only partly luminous, seems to fit in a hole in the sky. Even a casual inspection shows that this nebula can be feebly seen over the entire spot where all the stars are blotted out sharply, and that the absence of stars is due to the obscuring presence of the nebula. This object is really the key to the explanation of most of the dark regions of the sky.

4. The small black spot (No. 92) shown in the photographs in this *Journal* for December 1913,[2] where visual observations prove the existence of a material object.

To me these are all conclusive evidence that masses of obscuring matter exist in space and are readily shown on photographs with the ordinary portrait lenses. What the nature of this matter may be is quite another thing. Slipher has shown spectroscopically[3] that the great nebula about Rho Ophiuchi is probably not gaseous; that is, it does not have the regular spectrum of a gaseous nebula. The word "nebula," nevertheless, remains unchanged by this fact, so that we are free to speak of these objects as nebulae. For our purpose it is immaterial whether they are gaseous or non-gaseous, as we are dealing only with the question of obscuration. In the present paper it is intended to give a catalogue of some of these objects and to show further examples of obscuration and other peculiarities, and to try to emphasize the fact that they are not necessarily confined to the Milky Way but are found in other parts of the sky as well; and also to bring as much evidence as possible to prove that these extra-galactic objects show that space is itself more or less luminous.

Outside of these examples, where the object is partly luminous, there are a number of others which appear to be entirely devoid of light. These are naturally best shown on the bright background

[1] *Astrophysical Journal*, 25, 1907, Plate XI, facing p. 219, and Plate XII, facing p. 221.

[2] *Ibid.*, 38, 1913, Plates XIX and XX, facing p. 496.

[3] *Lowell Observatory Bulletin*, No. 75, 2, 155.

of the Milky Way, against which they appear black on the photographs. Fine examples of these Milky Way objects are the black spots in $\alpha = 18^h8^m$, $\delta = -18°16'$ (No. 92), and in $\alpha = 17^h55^m$, $\delta = -28°$ (No. 86), which are so striking in photographs of the star-clouds in Sagittarius.[1]

The last of these two is very remarkable when seen in a 5-inch telescope with a low power. In such an instrument it appears like a drop of black ink on the bright background of the Milky Way. It was found in my comet-seeking in the early eighties.[2] On account of its extreme blackness it was one of the most impressive objects in the Milky Way. I examined it with the 36-inch refractor of the Lick Observatory with a power of 350 and a field of 6′, on August 18, 1895. It nearly filled the field of view. The western half was fairly well defined, while the eastern half was more diffused. Considerable nebulosity seemed to be connected with it. A photograph on July 11, 1917, with the Crossley reflector, kindly sent me by Dr. H. D. Curtis, shows this black spot to be very remarkable, having considerable nebulosity connected with it. On his photograph its southwest side is very sharply defined, closely resembling in this respect the east side of the black spot in $\alpha = 18^h8^m$, $\delta = -18°16'$ shown in Plate XX.[3] Its east side, like the west side of the foregoing object, is more or less diffused. The star C.D. $-27°12302$ ($7^M.4$) is on the northwest border, while $-27°12310$ ($9^M.0$) is close east of the spot. The beautiful cluster of small bright stars, N.G.C. 6520, is also close east.

Visual observations actually show, however, that the object No. 92 is really feebly luminous. All those that are in the Milky Way are not necessarily devoid of light, for they may appear black by contrast with the greater brightness of the Milky Way. There are numerous examples, however, which are not in the Milky Way and which are perhaps entirely devoid of light. It would seem that such a body would be lost in the blackness of space, but they are

[1] See various plates in *Publications of the Lick Observatory*, 11, and especially Plates 49 and 54.

[2] See *Astronomische Nachrichten*, **108**, 370, 1884, where it is described as "a small triangular hole in the Milky Way. Perfectly black, some 2′ diameter, much like a jet black nebula."

[3] *Astrophysical Journal*, **38**, 496, 1913.

visible as black objects against space itself. I have previously explained this anomaly[1] by suggesting that space is probably filled with a feeble light which forms a slightly luminous background for these dark bodies. Further investigations have fully convinced me that this is actually the explanation of the phenomenon, for there is no evidence of an ordinary nebulous background in these cases. Furthermore, this feeble illumination is widespread and undoubtedly universal (so far, at least, as our stellar universe is concerned), for these dark objects are found in opposite parts of the sky, where there are few stars, and away from any possible brighter background.

One of the finest examples of a dark object seen against the ordinary sky and away from the Milky Way is No. 15, shown on the photographs in $\alpha = 4^h22^m50^s$, $\delta = +46°21'$. It is elliptical, 10′ by 15′ in diameter. The background on which the stars shine is uniform over the entire plate. The object is in a region somewhat larger than itself, where there are relatively few stars, and is black by contrast with the sky alone. It clearly shows the presence of a feeble uniform luminosity in space which, from the appearance of similar objects in widely different parts of the sky, leads to the belief that this feeble illumination of distant space is universal. If this object were seen against the star-clouds of the Milky Way it would appear strikingly black.

There is another and very similar black spot (No. 48) in $\alpha = 16^h53^m$, $\delta = -40°30'$, close west and north of the eighth magnitude star C.D. $-40°11088$. There can be no doubt that this is a material object. There are a number of other similar black masses in this region, as shown by the catalogue.

Another excellent example of this class of objects is No. 160, in $\alpha = 21^h34^m47^s$, $\delta = +55°41'$. The body of this marking is much broken with darker masses. It is convex to the north and passes just below (south of) B.D. $+59°2291$ ($8^M.0$). The western end curves to a slender "tail" which ends close southwest of B.D. $+59°2283$ ($8^M.2$). The eastern end widens out into a large "head" containing much detail, which is more or less convoluted, with sharply defined projections like the horns of an insect.

[1] *Astrophysical Journal*, 43, 1, 1916.

There seems to be no question but that this is a real, opaque object seen in projection against space. The stars in this region are too few to serve as a luminous background and there is no nebulosity to show it in dark relief, yet it stands out black and strong against the sky.

In previous papers I have dealt mainly with the larger dark masses and occulting nebulosities. The smaller ones that are now treated of are perhaps more interesting in a way than the larger ones. They are more definite and in a sense more clearly show the effect of obscuration of the smaller stars.

The small scale of the portrait lens accentuates the blackness and definiteness of these objects. This is a valuable asset in such a lens; it draws attention to peculiarities which might be lost by diffusion with a more powerful telescope. They are worthy of a careful study, however, with some of the large photographic reflectors. This has already been done, as I have stated, in the case of the black spot (No. 86) in $\alpha = 17^h55^m$, $\delta = -28°$, by Dr. H. D. Curtis with the 36-inch Crossley reflector of the Lick Observatory. I am sure that some of the objects shown in the present photographs will give very interesting results when similarly investigated.

There are two regions which can be reached from the northern hemisphere that are specially rich in these dark markings: (1) the region immediately north of Theta Ophiuchi; (2) the region of the great star-cloud in Scutum near the cluster M 11. There are other regions in which black markings occur, but these two contain the most striking ones, striking for their smallness and peculiarities.

Some of the dark objects in the remarkable region north of Theta Ophiuchi are so strange in their forms that we would find it difficult to match them with similar forms among the real nebulae. This in itself would almost discourage the supposition that they are dark nebulae, and one would rather seek some other explanation for them. In other parts of the sky, however, there seems to be no need of hesitation in accepting them as real, obscuring masses, most probably dark nebulae.

Perhaps one of the finest of the large dark regions (No. 78) lies several degrees southeast of Theta Ophiuchi. It is a large, irregular, dark spot some 3° in diameter and less definite on the eastern

side. There is considerable detail in it of a more or less nebulous character. This is specially evident near the bright star C.D. $-26°12152$ ($6^{M}.2$). Westward from this region a broken dark lane extends for about 5° to what I have called the "sink hole," because of its peculiar form and outlines. This sink hole (No. 59) is full of rich detail. Similar structural detail shows at frequent intervals along the broken lane (which is about $\frac{3}{4}°$ wide) to its origin in the larger dark region southeast of Theta Ophiuchi. Splendid half-tone reproductions of this remarkable region have been published in *Popular Astronomy*.[1]

The bright nebulae seldom show extraordinary forms. Some of them, however, exhibit structural details and general forms that are very remarkable and that sometimes are very beautiful, such as the zigzag, streaky, or "lace" nebula in Cygnus, the great nebula of Orion, and many of the planetary nebulae. It is possible then that the objects north of Theta Ophiuchi are, after all, only exceptions to the general run of nebulous forms and are similar to such objects as those in Cygnus and elsewhere among the bright nebulae.

A peculiarity of the dark markings in the star-cloud in Scutum is that some of the well-defined spots are uniformly gray, while others are either entirely black or have much blacker, well-defined spaces in them. In nearly every case their outlines are very definite and few have stars in them.

To the east of the $4^{M}.5$ star B.D. $-4°4582$ (δ Aquilae) and north of the cluster M 11 is a beautiful region of dark structures (No. 111). It forms a wide crescent with the convex side to the west, sharply bounded by the neck and head of the splendid star-cloud in which M 11 is placed. It is irregular and broken to the east. Its width north and south is about 2°. This area is full of dark structures, the more conspicuous ones being Nos. 106, 107, 110, and 113. The two stars B.D. $-5°4775$ ($8^{M}.3$) and $-5°4778$ ($8^{M}.4$) are near the middle of this region. The center would be in about $\alpha = 18^{h}44^{m}$, $\delta = -5°\,6'$.

In many cases one side of a dark marking is very definite, while the other side is diffused. This occurs so often that there must

[1] *Popular Astronomy*, 14, 579 (December), 1906, Plates XIII and XIV.

be some reason for it. The same peculiarity is sometimes seen in the bright nebulae, the great nebula of Orion being a striking example. Three of these objects, which are very much alike, and which show this feature strongly, are No. 50, $\alpha = 16^h54^m42^s$, $\delta = -34°12'$; No. 143, $\alpha = 19^h35^m30^s$, $\delta = +10°43'$; No. 160, $\alpha = 21^h33^m40^s$, $\delta = +55°40'$. The first two very closely resemble each other in size and form and the third differs from them only in a small degree.

The dark object (No. 133) close to the 9^M2 star B.D. $-7°4852$, which looks like a negative of a comet with a curved tail, more or less fan-shaped, was examined with the 40-inch telescope July 14, 1917 (see Fig. 1). It was clearly evident that there is a faint hazy object

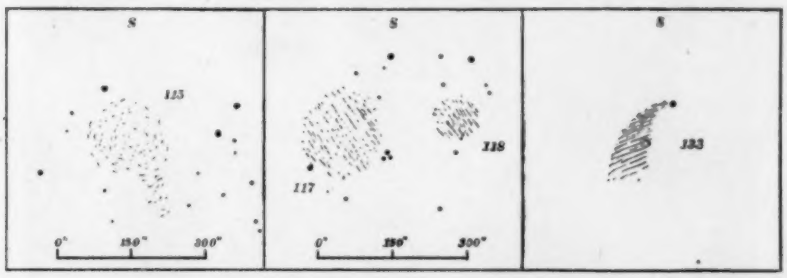


FIG. 1.—Sketched from visual observations of Nos. 115, 117, 118, and 133, with the 40-inch telescope.

at this place. It is dull and feebly luminous compared with the adjacent sky. It is very dark at its south end and curves northward for nearly 10′. The northern part, which is more diffused, is broken by a few faint stars. Obscuring matter of some kind certainly exists at this point. Furthermore, it is not black except by contrast. In this respect it very much resembles the dark object (No. 92) in $\alpha = 18^h8^m$, $\delta = -18°16'$, which was examined with the 40-inch telescope in July 1913.[1] Two other objects, Nos. 127 and 129, were carefully examined on this date. The object No. 127 is similar except in form to the one just described. It seems to be a dull, feebly luminous mass as in the case of the other, with no definite outline. Sweeping rapidly over these objects with the telescope

[1] See *Astrophysical Journal*, 38, 496–501, 1913.

there is no hesitation as to their actual presence where the photograph shows them. There is no evidence of ordinary nebulosity at these points except the feeble, dull appearance described.

One remarkable thing in this visual investigation is the conspicuousness of the B.D. stars everywhere, while on the photographs

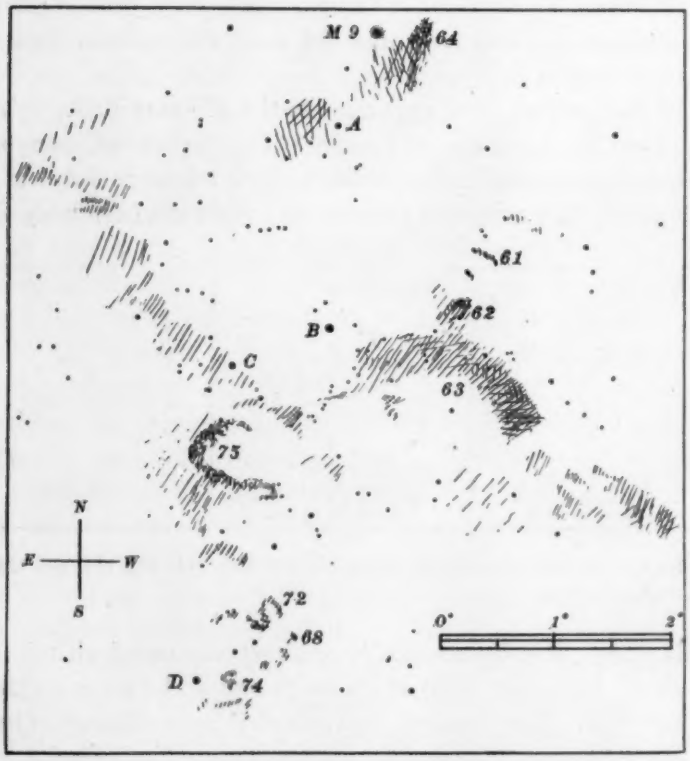
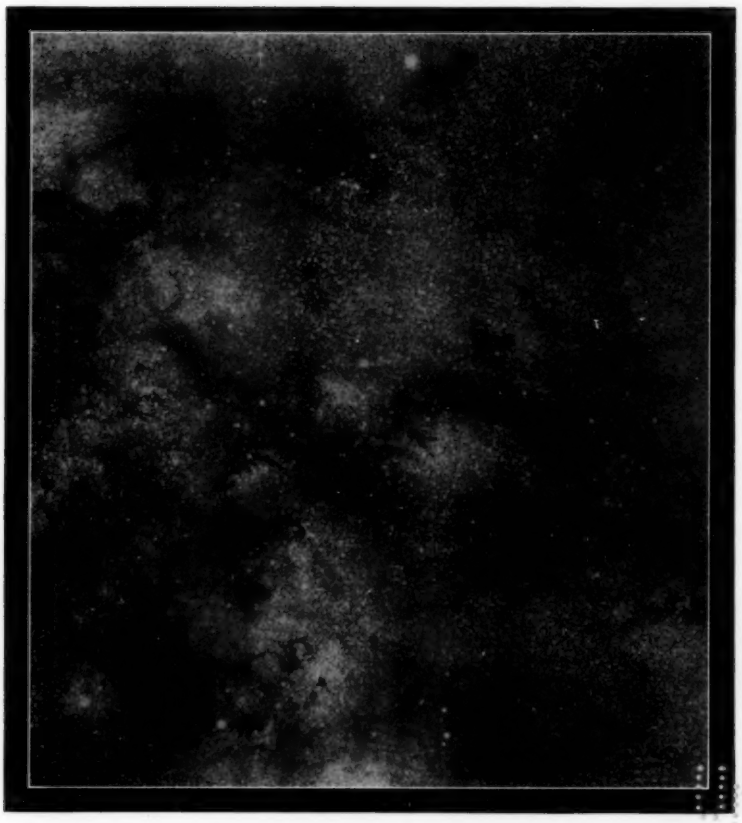


FIG. 2.—Sketch map of Plate I

they are difficult to make out. Evidently the sky comes up luminous on the photographs from the myriads of small stars not seen in the telescope. It is this general effect of unseen stars which do not show individually, either in the telescope or on the photograph, that helps to round out the great star-cloud. Doubtless there is not a star on the plate that cannot be seen in the large telescope, but I am not sure of this. It is mainly the light from unseen stars that makes the white background of the photographs against which the dark markings show so conspicuously.

PLATE I

North

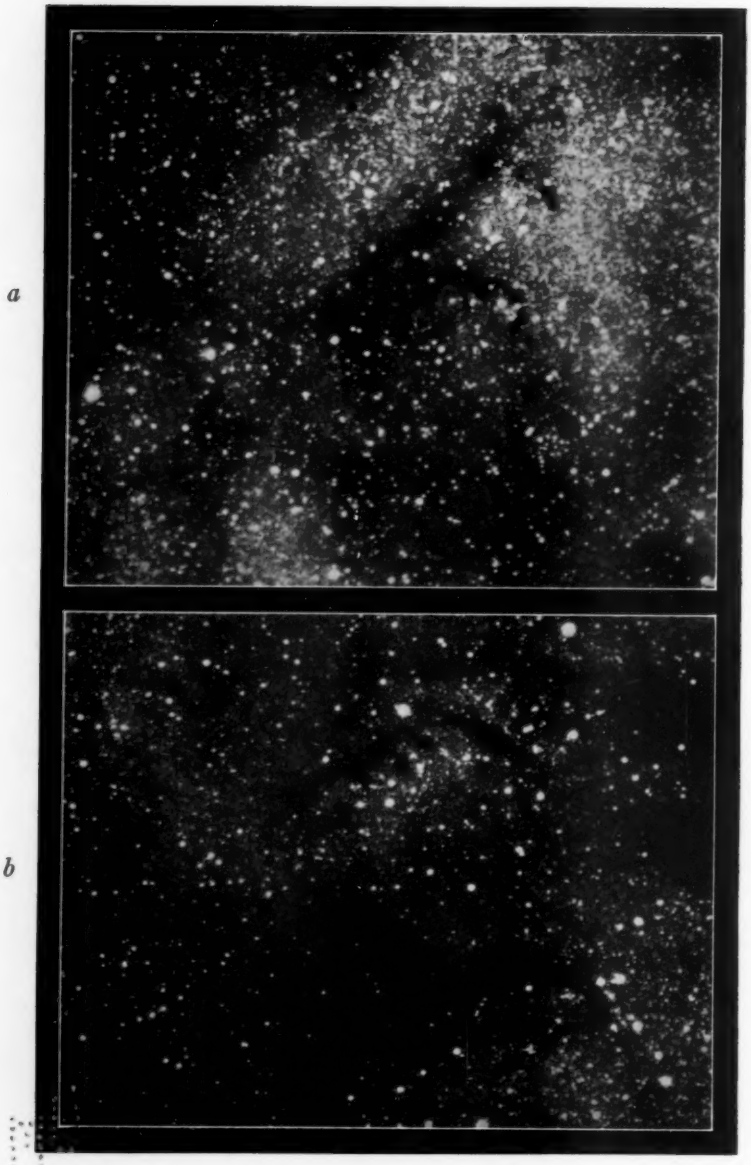


REGION NORTH OF THETA OPHIUCHI
$\alpha = 17^h\ 13^m$, $\delta = -21^\circ\ 0'$

Scale: $1^{mm} = 234''$

PLATE II

North



a

b

a) No. 84. $\alpha = 17^h39^m$, $\delta = -20°12'$. Scale: $1^{mm} = 49''$
b) No. 75. $\alpha = 17^h18^m$, $\delta = -21°55'$. Scale: $1^{mm} = 59''$

In these observations the sky was satisfactory and the seeing fairly good. To me the result is conclusive that these markings are real objects seen in dark relief on the bright background of the Milky Way. They are certainly not holes in the star-cloud. The definite outlines which appear so striking on the photographs are not seen in the sky. They are lost through the great magnifying power of the telescope. On July 18, 1917, the small objects Nos. 115, 117, and 118 were similarly examined and sketches made. The spot No. 118 shows some detail, or different degrees of darkness, while No. 117 is uniformly dark or dusky.

The great partially dark nebula (No. 7) in $\alpha = 4^h 4^m 14^s$, $\delta = +28°28'$, reference to which has already been made in the beginning of this paper, is irregularly round, with a wide extension to the west to about $\alpha = 4^h 1^m$, $\delta = +27\frac{1}{2}°$ or $+28°$. The object is unevenly dark with a brighter condensation in its eastern part. Its diameter along the east and west extension is 2°; north and south its diameter is 1°.2. The bright condensation (No. 10) is 8′ in diameter and is in $\alpha = 4^h 10^m 57^s$, $\delta = +27°58'$. There are several small, round, black spots in the northern part of the dark nebula. Their approximate positions are:

α	δ	
$4^h\ 8^m\ 6^s$	$+28°31'.0$	Indefinite; diameter 8′
4 9 26	+28 20.5	Round; diameter 5′
4 10 10	+28 21.6	Round; diameter 5′
4 10 44	+28 9.5	Length 15′ north and south; width 5′; involving B.D. +28°637 (9^M5)

The region for some distance about this great dark nebula is very remarkable and suggestive. Beginning at about $\alpha = 4^h 9^m 50^s$, $\delta = +27°25'$, an irregular dark lane about 10′ wide with unequal dark markings in it runs southeast for $2\frac{1}{2}°$ nearly to another large obscure nebula (No. 22). A similar dark lane beginning at a group of large dark spots (No. 18) in $\alpha = 4^h 23^m 40^s$, $\delta = +24°5'$, runs westerly in a curved and irregular manner for about 4°.

These lanes are all definite and dark on the sky, independent of the background of stars.[1] There are indications of considerable

[1] See *Astrophysical Journal*, **25**, 218, 1907, where photographs of the region are given.

areas of feeble nebulosity for several degrees in this region. These will be treated of in a later publication.

No. 144 of the catalogue is a very large, unequally dark area in a very rich region of the Milky Way. Its general outlines are fairly distinct and somewhat abrupt except toward the south, where it widens out and becomes lost in the general groundwork. Over this large area the dense background of small stars is wanting, but there are scattered over it everywhere a great many stars, big and little. Its eastern side near the north end is partly covered by a protrusion over it of the denser part of the Milky Way, which quite obliterates it for a degree or more. The northern end of this area is more or less rounded and is terminated at the northeast side by a sharper projection in $\alpha = 20^h 3^m$, $\delta = +36\frac{1}{2}°$. This great partial vacancy is probably due to an actual thinning out of the small stars in this region, for it does not have the appearance of obscuring matter.

To illustrate the remarkable appearance of some of these objects the accompanying half-tone plates have been prepared. These show the peculiarities as they appear on ordinary portrait-lens photographs. The brief descriptions of the objects shown in the illustrations are based on an examination of the original negatives. The engravings are good, but they fail to show the more delicate structures which are so clear on the photographs and are such important features of these objects. Therefore, if there should be any difficulty in identifying all the features described, it must be attributed to the failure of the half-tones to show them.

DESCRIPTION OF THE PLATES

PLATE I

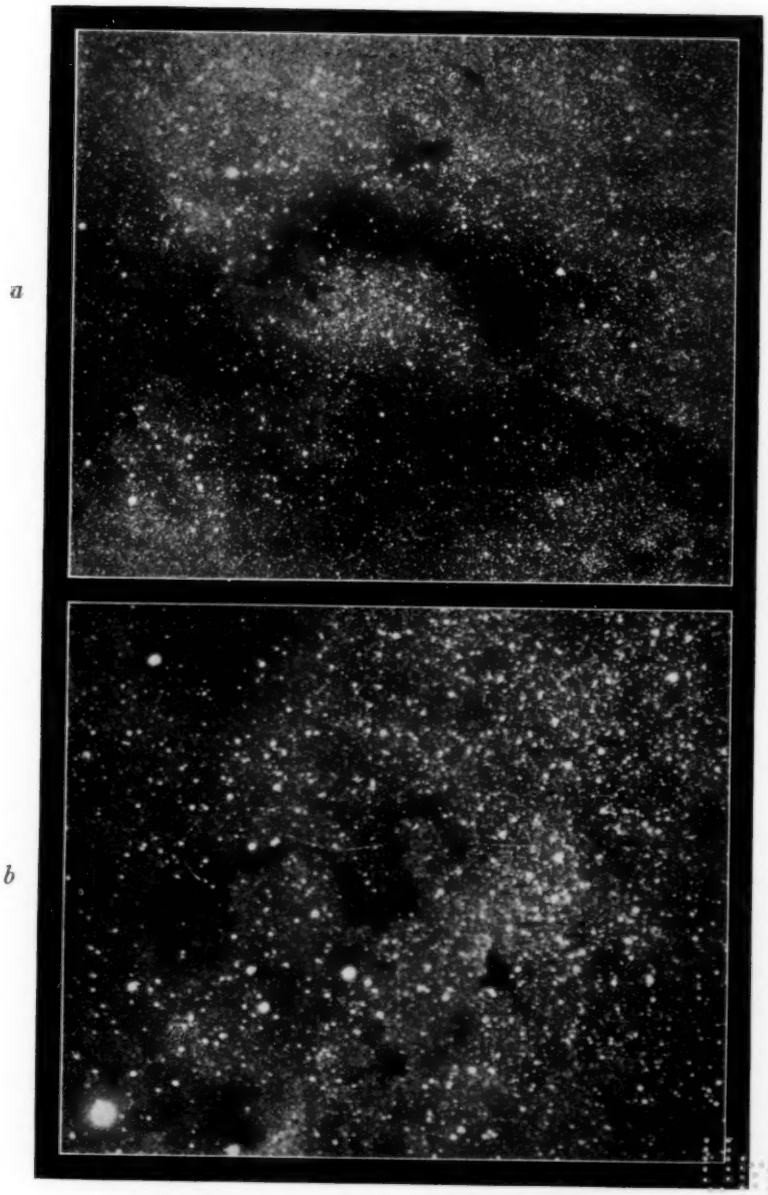
This shows the region north of Theta Ophiuchi and its rather fantastic markings as a whole. The glow from Theta is seen at the lower edge of the plate. By comparing this picture with the chart (Fig. 2) the relative positions of the various objects shown in some of the other plates can readily be seen.

PLATE II

Two of these queer markings are shown here, the lower being readily recognized as one of those on Plate I. It is a curious, narrow, looped, black marking (No. 75) that covers about a degree in its peculiar windings. It

PLATE III

North



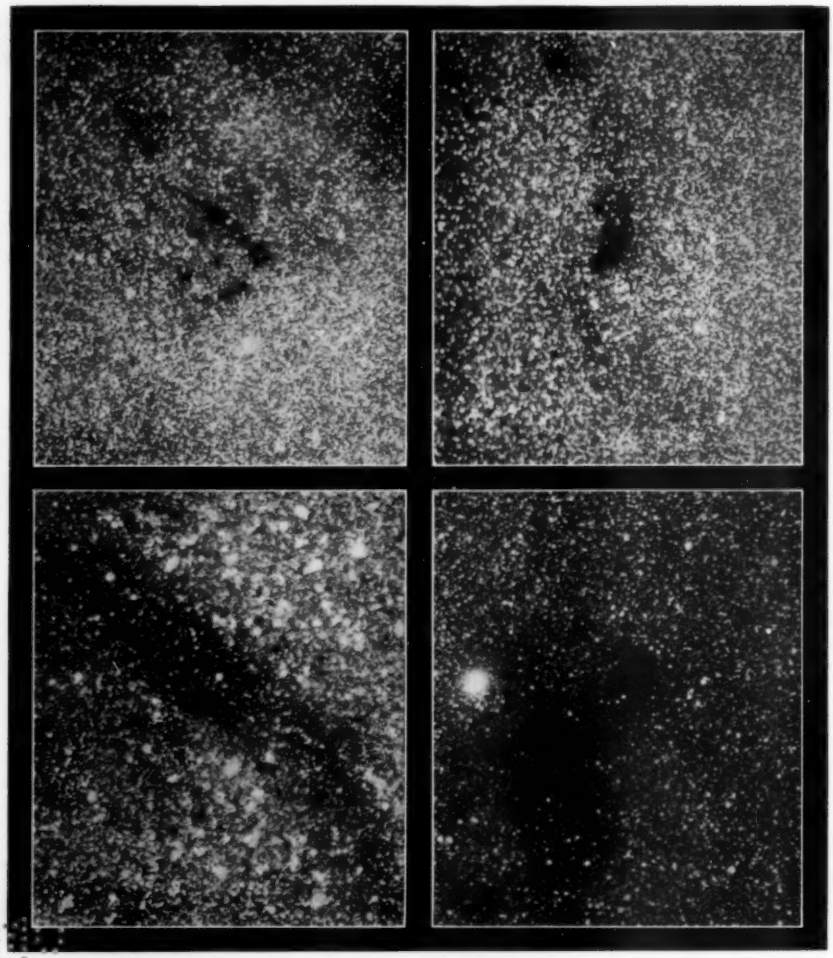
a

b

a) No. 63. $\alpha = 17^h\ 9^m$, $\delta = -21°17'$. Scale: $1^{mm} = 160''$
b) No. 72. $\alpha = 17^h 16^m$, $\delta = -23°37'$. Scale: $1^{mm} = 60''$

PLATE IV

North



a) Nos. 127 and 129. $\alpha = 18^h55^m$, $\delta = -5°37'$
Scale: $1^{mm} = 93''$

b) No. 133. $\alpha = 18^h59^m$, $\delta = -7°5'$
Scale: $1^{mm} = 89''$

c) No. 98. $\alpha = 18^h26^m$, $\delta = -26°9'$
Scale: $1^{mm} = 63''.5$

d) No. 64. $\alpha = 17^h10^m$, $\delta = -18°21'$
Scale: $1^{mm} = 78''$

occupies a considerable space and one position will not represent its place. The upper or north part of it is in $\alpha = 17^h17^m44^s$, $\delta = -21°51'$. From this point it bends to the east, passing close south of the star B.D. $-21°4598$ (8^M3) and then south and west to an abrupt stop in $\alpha = 17^h15^m44^s$, $\delta = -22°21'$. A diffused branch springs from it and curves easterly and southwest again in a very broken manner. At this point there is much dark detail of an irregular nature. Close north and west of this object, just above (and involving) the star B.D. $-21°4591$ (9^M5) is a very dark, irregular figure (No. 67*a*).

This marking is almost exactly duplicated in its scalloped appearance by a similar one (No. 84) in $\alpha = 17^h39^m$, $\delta = -20°12'$, which is shown in the upper picture of this plate. It lies between the stars B.D. $-20°4865$ (8^M2) and $-20°4869$ (9^M1) and curves a little to the north. The resemblance of these two strange objects and their peculiar character is very striking.

PLATE III

These are two more of the dark objects north of Theta Ophiuchi. The upper one (No. 63) is the very large definite curved marking. Its southwest end strikingly and abruptly terminates in $\alpha = 17^h6^m14^s$, $\delta = -21°41'$. In the original negative there is much dark detail in this object.

The lower picture shows the S-shaped marking (No. 72) in $\alpha = 17^h16^m17^s$, $\delta = -23°37'$, and several of the very black spots south of it.

PLATE IV

The upper right-hand object (No. 133) resembles a dark comet with a small definite head and curved fan-shaped tail. The main body seems to be a sharply defined, black, lozenge-shaped object which forms the head and part of the body, from which a diffused extension runs north, forming the tail of the "comet." A description of the visual appearance of this object with the 40-inch telescope is given in the present paper, page 7. The position of the dark head, which lies very close west of the star B.D. $-7°4852$ (9^M2), is $\alpha = 18^h59^m29^s$, $\delta = -7°4'.8$.

The picture immediately beneath this one, to the right, is that of a similar "cometary" object (No. 64), just west of the compressed cluster M 9. It is somewhat cometary in form and has a very black core or head that sharply abuts against the thick stratum of stars; from this it spreads out into a large dark area with much dark detail, filling quite a space close southwest of M 9. It thus resembles a dark comet with a dense and well-defined head and diffused widening tail. The position of the head is $\alpha = 17^h9^m57^s$, $\delta = -18°20'.6$.

The upper left picture of this plate shows a chain of several dark spots, two of which (Nos. 127 and 129) are quite small, black and irregular in form. The northern one (No. 129) has a very narrow black streak running from it to the northeast. I have examined these also with the large telescope with a result similar to that of the spots previously mentioned. Their position is $\alpha = 18^h55^m$, $\delta = -5°40'$.

In the fourth, or lower left, picture is a small, round, well-defined, black spot (No. 98) less than 3′ in diameter. This could readily be taken for a black planetary nebula, which, in reality, it may be. Its position is closely $\alpha = 18^h 25^m 31^s$, $\delta = -26°9'$. It is not seen on a bright part of the sky for it lies in, and near the south edge of, a rather broad dark pathway in the Milky Way. It is some 3′ south and following the star C.D. $-26°13264$ (10^M).

I did not at first believe in these dark obscuring masses. The proof was not conclusive. The increase of evidence, however, from my own photographs convinced me later, especially after investigating some of them visually, that many of these markings were not simply due to an actual want of stars, but were really obscuring bodies nearer to us than the distant stars. In this way it has fallen to my lot to prove this fact. I think there is sufficient proof now to make this certain. For some years I have tried to secure long-exposure photographs of as many of these bodies as possible. This has resulted in the location of a considerable number of them in different parts of the sky. Their apparent preference for the bright regions of the Milky Way is obviously due to the fact that they are more readily shown with a bright background. They are, however, not strictly confined to the Milky Way.

Among the first to look upon these dark places as real matter was Mr. A. C. Ranyard, whose lamentable death occurred December 14, 1894. A short time previous to his death he gave a series of papers on the Milky Way and the nebulae, in *Knowledge*, of which magazine he was editor. In speaking of the dark lane south and east of Theta Ophiuchi on a Lick photograph of mine which he reproduced,[1] he says: "The dark vacant areas or channels running north and south of the bright star [θ Ophiuchi] at the center . . . . seem to me to be undoubtedly dark structures, or obscuring masses in space, which cut out the light from the nebulous or stellar region behind them."

There is a list of starless fields given in Appendix I of Webb's Celestial Objects, taken from the Cape observations of Sir John Herschel. These, however, are quite different from the ones I have been dealing with and are in most cases perhaps only real vacancies among the stars.

[1] *Knowledge*, **17**, 253 (November) 1894.

For some time I have hoped to make a catalogue of the dark markings shown on my photographs of the sky. The exact location of these objects is desirable so that their study with powerful photographic telescopes may be possible. There seems to be no question that some of them are real objects which are either entirely devoid of light or so feebly luminous when seen against the Milky Way as to appear black. As mere curiosities of the sky alone their cataloguing would be desirable, but as real opaque objects between us and the more distant stars their exact location would seem to be important. Their study with the present means of research will be of the highest interest. With this idea in view I have collected a number of these objects shown on my negatives to form the following catalogue.

This catalogue is necessarily incomplete; it is constantly being added to. Later, a more complete list will be printed. The places are closely approximate. An effort was made to measure the positions with exactness, but on account of the nature of the objects it was found to be practical to do this in only a few cases.

All the positions in the catalogue and throughout this paper refer to the epoch 1875.0.

NOTES ON THE CATALOGUE

No.

8 Very much like the dark lanes east of Rho Ophiuchi.

9 This is the middle of a great vacancy extending east and west, the continuous part of which is $2\frac{1}{2}°$ long and about $\frac{1}{2}°$ wide. It really extends in a more or less broken form for about 6°. There is a wide region extending south of it for a couple of degrees, nearly to the star B.D. $+53°$ 750 ($5^{M}0$) whose position is $\alpha = 4^{h}6^{m}58^{s}$, $\delta = +53°18'$. To the east it breaks up into more or less separate spots, somewhat resembling those at the east end of the great lane from Rho Ophiuchi, but unlike that lane it does not originate in a larger vacant space or a nebula. Its borders are not so definite as the Rho Ophiuchi lane. It is approximately bounded by the co-ordinates $\alpha = 3^{h}58^{m}$, $\delta = +54°7$ and $\alpha = 4^{h}20^{m}$, $\delta = +54°8$. The individual positions of some of the spots are given in the catalogue.

11 This lane is about 2°6 long and roughly 22′ across. It is very much like the lanes east of Rho Ophiuchi. See No. 8.

12 South of No. 11. Irregularly round with an extension east from the northeast side.

CATALOGUE OF 182 DARK MARKINGS IN THE SKY

No.	α 1875.0	δ 1875.0	Description
1.....	$3^h25^m14^s$	+30° 44′	Large, indefinite; diam. ½°
2.....	3 25 44	+31 54	Indefinite; elongated east and west; diam. 20′
3.....	3 32 14	+31 34	Irregular; diam. 20′; dark space in nebula
4.....	3 36 14	+31 24	Very large; indefinite
5.....	3 39 15	+32 8	Indefinite; elongated northeast and southwest; diam. 1°. B.D. +32°667 (5^M8) near northeast side
6.....	3 46 31	+55 45	Round; indefinite
7.....	4 4 14	+28 28	Large, irregular; brighter condensation in southeast part
8.....	4 7 53	+54 56	The center of No. 11
9.....	4 9	+54 45	Dark irregular lane
10.....	4 10 57	+27 58	The bright part of No. 7
11.....	4 16 37	+54 45	East end of irregular lane
12.....	4 19 52	+53 58	Isolated dark spot; diam. 24′
13.....	4 21 17	+54 37	Irregular; diam. 11′
14.....	4 22 13	+25 31	Very small, bright nebula; diam. 3′
15.....	4 22 50	+46 21	Elliptical dark marking; diam. 10′ by 15′ slightly northwest and southeast
16.....	4 23 20	+46 20	Very small; elongated north and south; close to southeast edge of No. 15
17.....	4 23 25	+46 15	Very small; elongated north and south; close to east edge of No. 15
18.....	4 23 40	+24 5	Diam. 1°; group of dark spots
19.....	4 25	+26 0	Large; indefinite; diam. 1°
20.....	4 27 30	+50 43	In the south part of larger, relatively vacant area nearly 1° in diam.
21.....	4 27 51	+55 6	Indefinite; irregularly round; diam. 10′
22.....	4 31	+25 48	Irregular; unequally dark; extended southeast and northwest; diam. 2°
23.....	4 32 41	+29 38	Diam. 5′; sharply pointed to the southeast
24.....	4 35 0	+29 30	Diam. 8′; sharply pointed to the south
25.....	4 42 56	+45 48	Irregularly round; diam. 8′
26.....	4 46 39	+30 25	Irregular; diam. 5′
27.....	4 47 11	+30 21	Irregular; diam. 5′
28.....	4 47 54	+30 26	Irregular; diam. 4′
29.....	4 58 5	+31 55	Round; indefinite; diam. 10′
30.....	5 23 8	+12 21	Large dark area with few stars; diam. 67′
31.....	5 25 8	+12 38	Diam. 30′; extended northeast and southwest; the east part of No. 30
32.....	5 25 8	+12 20	Dark projection from the south end of No. 31 to the east
33.....	5 34 36	− 2 32	Dark mass, diam. 4′, on nebulous strip extending south from ζ Orionis
34.....	5 35 20	+32 21	Round; starless; indefinite; diam. 20′
35.....	5 39 5	+ 8 51	Round; diam. 13′
36.....	5 43 5	+ 7 23	Irregular narrow dark lane 2° long, northeast and southwest
37.....	6 26 14	+10 34	Irregular semi-vacant region 2½°–3° long
38.....	6 26 45	+11 10	Irregular vacancy; diam. 1°
39.....	6 31 8	+10 26	Small, sharply defined.
40.....	16 7 24	−18 39	Diffused dark spot; diam. 15′; small star in it
41.....	16 14 24	−19 20	Diffused dark spot; diam. ¾°
42.....	16 18	−23 9	Great nebula of ρ Ophiuchi

CATALOGUE OF 182 DARK MARKINGS IN THE SKY—*Continued*

No.	α 1875.0	δ 1875.0	Description
43.....	16^h23^m s	−19° 30′	Large dark region
44.....	16 33	−23 50	Dark lane east from Rho Ophiuchi region
44*a*....	16 38 8	−40 6	Round; diam. 2′. Close south of C.D. −40°10662
45.....	16 39 11	−21 22	Rather definite, 2° long
46.....	16 49 42	−22 32	Irregular; definite
47.....	16 52 12	−22 27	Irregular; definite; diam. 15′
48.....	16 53	−40 30	Fairly well defined; 26′ long
49.....	16 54 30	−33 5	Small; close southeast of and involving C.D. −33°11668 (9^M3)
50.....	16 54 42	−34 12	Large, irregular, dark space; 10 mag. star in middle
51.....	16 56 12	−22 12	Definite; diam. 20′
52.....	16 57 14	−22 2	Irregular; diam. 13′
53.....	16 58	−33 25	Large; diffuse, extended north and south
54.....	16 58 30	−34 10	Small, round; diam. 5′; close north of 11 mag. star
55.....	16 59 28	−31 51	Irregular; diam. 16′; best defined southeast
56.....	17 0 43	−31 56	Small; diam. 3′
57.....	17 0 50	−22 43	Diam. 5′; elongated northeast and southwest
58.....	17 2 30	−40 20	Round; diam. 27′; a darker core at northeast side
59.....	17 3 35	−27 19	Sink hole; diam. 1°
60.....	17 4 21	−22 17	Curved; 13′ long; extended northeast and southwest
61.....	17 7 26	−20 18	Small; elongated east and west
62.....	17 8 46	−20 44	Diam. 19′; very black in northwest part
63.....	17 9 19	−21 17	Very large; definite; curved; west end abrupt
64.....	17 9 57	−18 21	Cometary; west of M 9
65.....	17 11 50	−26 34	Definite; elongated east and west
66.....	17 12 2	−26 46	Definite; extended east and west; 8′ long
67.....	17 13 14	−26 44	Definite; extended north and south; joins Nos. 65 and 66
67*a*....	17 14 58	−21 46	Irregular; definite; diam. 13′
68.....	17 15 4	−23 40	Small; irregular; sharply defined; diam. 4′; southwest of No. 72
69.....	17 15 19	−23 48	Very small; irregular; sharply defined; extends north and south 4′
70.....	17 15 30	−23 55	Diam. 4′; sharply defined on west side
71.....	17 15 36	−23 53	Very small; diam. $1\frac{1}{4}$±
72.....	17 16 17	−23 37	S-shaped
73.....	17 16 46	−24 9	Very small; diam. 1′; extended north and south
74.....	17 17 30	−24 2	Diam. 5′
75.....	17 17 47	−21 55	Curved and scalloped marking
76.....	17 18	−24 18	Irregular; narrow
77.....	17 21	−23 45	Indefinite; diam. 1°
78.....	17 25	−25 30	Very large; diam. 3°
79.....	17 27 44	−19 19	$\frac{1}{2}$° long (southeast and northwest); narrow; sharply defined
80.....	17 30 16	−21 11	Small; definite; 3′ long, 1′ wide, southwest and northeast
81.....	17 30 55	−23 51	Very small; diffused
82.....	17 31 0	−23 42	Small; angular; well defined
83.....	17 31 20	−24 6	Irregular; diam. 7′
83*a*....	17 37 57	−19 57	Small, definite; diam. north and south 4′
84.....	17 39	−20 12	Sharply defined; length north and south 22′
84*a*....	17 48 40	−17 9	Round; diam. 16′; extension $\frac{3}{4}$° south
85.....	17 53 50	−23 1	Trifid nebula. See note

CATALOGUE OF 182 DARK MARKINGS IN THE SKY—*Continued*

No.	α 1875.0	δ 1875.0	Description
86.....	$17^h55^m\ 9^s$	−27° 52′	Diam. 5′; several small stars in it
87.....	17 56 14	−32 6	"Parrot's head"; C.D. −32°13686 (9^M8) central; several smaller stars in it
88.....	17 56 56	−24 7	Length north and south 2′.7, width 0′.5; in M 8
89.....	17 57 20	−24 22	Very small; diam. 0′.5; in M 8
90.....	18 2 20	−28 18	Irregular; diam. 2′.7
91.....	18 2 30	−23 43	Diam. 5′; edge of diffused nebulosity
92.....	18 8 16	−18 16	Black spot, 15′ north and south, 9′ east and west
93.....	18 10 14	−17 52	Cometary
94.....	18 18 37	−10 44	Roundish; diam. 15′; indefinite
95.....	18 18 37	−11 49	Large; indefinite; diam. 30′; elongated
96.....	18 19 7	−10 19	Small; indefinite; elongated
97.....	18 23 7	−10 0	Irregular; not very definite; diam. 1°
98.....	18 25 31	−26 9	Very small; sharply defined
99.....	18 25 48	−21 34	Definite; 11′ long east and west, 3′ wide
100.....	18 26 7	− 9 14	Definite; irregular; curved; 16′ long northwest and southeast
101.....	18 26 7	− 8 54	Definite; irregular; 13′ long northeast and southwest, 4′ wide
102.....	18 30 37	−13 51	Rather definite; 8′ long northeast and southwest, 3′ wide
103.....	18 32 42	− 6 47	Irregular; diam. 4′; one small star in it
104.....	18 40 42	− 4 47	Small, definite, caret-shaped object
105.....	18 41 2	− 7 3	Very small; diam. ½′; close northeast of B.D. −7°4710 (8^M9)
106.....	18 42 11	− 5 13	Diam. 2′; extended north and south; free of stars
107.....	18 42 52	− 5 9	Irregular; diam. 5′; free of stars
108.....	18 42 52	− 6 27	Very small, diam. 3′
109.....	18 42 57	− 7 43	Irregular; diam. 0′.7; close east of B.D. −7°4726 (8^M0)
110.....	18 43 30	− 4 59	Irregular; diam. 11′
111.....	18 44	− 5 6	Region 2° in diam., full of dark structures
112.....	18 44 25	− 6 49	Diffused dark region; diam. 18′±
113.....	18 44 43	− 4 28	Diam. 16′; irregular; small star in west part
114.....	18 46 27	− 7 6	Dark spot with two small stars in it
115.....	18 46 36	− 6 49	Very small and black
116.....	18 46 48	− 7 11	Narrow semi-vacant region running south from B.D. −7°4755 (9^M1)
117.....	18 46 58	− 7 34	Round; very black; diam. 1′; sharply defined
117a....	18 47 4	− 5 0	Black; irregular; diam. 7′
118.....	18 47 10	− 7 36	Definite; diam. 2′
119.....	18 47 59	− 4 42	Very small; close northwest of B.D. −4°4623 (9^M2)
119a....	18 48 0	− 5 20	Irregular dark region; diam. ½°
120.....	18 48 16	− 4 45	Very small; close southeast of B.D. −4°4623 (9^M2)
121.....	18 48 48	− 4 46	Small dusky spot; 12 mag. star in center
122.....	18 50 11	− 4 55	Small; diam. 4′; narrow extension 4′ north
123.....	18 51 2	− 4 53	Roundish; diam. 1½′
124.....	18 51 5	− 4 31	Small dark spot; diam. 3′
125.....	18 51 45	− 4 33	Dark; lune-shaped; diam. 9′
126.....	18 52 25	− 4 42	Dusky; round; rather definite; diam. 8′
127.....	18 54 52	− 5 37	Irregular; diam. 4½′
128.....	18 55 3	− 4 45	Irregular; dusky; fairly well defined; diam. 10′
129.....	18 55 3	− 5 29	Very black; sharply defined; diam. 5′
130.....	18 55 16	− 5 45	Dusky; not well defined; length 7′

CATALOGUE OF 182 DARK MARKINGS IN THE SKY—*Continued*

No.	α 1875.0	δ 1875.0	Description
131.....	$18^h55^m39^s$	− 4° 33′	Black spot; diam. 0′.7; curve of small stars north
131a....	18 56 32	− 4 31	Diam. 3′
132.....	18 57 51	− 4 37	Dark; fairly well defined; diam. 8′
133.....	18 59 29	− 7 5	Cometary; close west of B.D. −7°4852 (9^M2)
134.....	19 0 11	− 6 26	Round; diam. 6′
135.....	19 0 57	− 4 7	Large dusky spot; diam. 13′
136.....	19 3 0	− 4 12	Dusky spot; diam. 8′; 10 mag. star near middle
137.....	19 9 32	− 1 33	Projection near south end of No. 138
138.....	19 10	0 0	Great curved semi-vacant lane over 3° in length
139.....	19 11 32	− 1 38	Narrow black spot; 10 mag. star on southeast edge
140.....	19 13 39	+ 4 59	Semi-vacant region; diam. 1°
141.....	19 13 52	+ 1 40	Semi-vacant region north of north end of No. 138; diam. 16′
142.....	19 34 0	+10 18	Large; irregular; close west of B.D. +10°4016 (8^M7)
143.....	19 35 30	+10 43	Rather narrow angular marking
144.....	19 54	+34 30	Large semi-vacant region; 6° by 3°
145.....	19 58 16	+37 21	Sharply defined; ¾° long east and west
146.....	19 58 49	+35 40	Very small
147.....	20 2 7	+35 1	Very narrow sinuous dark lane 11′ long east and west
148.....	20 45 30	+59 12	Very small; round; indefinite; diam. 3′
149.....	20 46 28	+59 4	Very small; round; indefinite; diam. 2′
150.....	20 47 47	+59 50	Curved dark marking; 1° long
151.....	21 4 41	+55 49	Very small; very dark; diam. 1′
152.....	21 11 30	+61 13	Small; 15′ by 3′ southeast and northwest
153.....	21 17 42	+55 55	Black, irregular; diam. 1′
154.....	21 18 1	+56 5	Narrow; 8′ long northeast and southwest
155.....	21 27 25	+44 25	Round; diam. 13′; indefinite
156.....	21 29 17	+45 2	Diam. 8′; sharp-pointed to north
157.....	21 29 34	+54 1	Round; diam. 5′
158.....	21 32 22	+42 51	Dark spot; diam. 3′
159.....	21 33 30	+42 40	Irregular partially vacant region; diam. 25′
160.....	21 33 40	+55 40	Large, dark, irregular; diam. 31′ northeast and southwest
161.....	21 36 38	+57 5	Small, black spot
162.....	21 37 8	+55 55	Very thin, curved, dark strip north and south
163.....	21 37 38	+56 5	Small; very black; pointed to the south
164.....	21 42 2	+50 31	V-shaped vacancy; diam. 5′–10′
165.....	21 45 10	+59 38	Length east and west 18′, width 1′
166.....	21 47 16	+59 30	Round; diam. 5′; small star on southwest edge
167.....	21 48 8	+59 29	Small; irregularly round; diam. 5′
168.....	21 48 32	+46 41	Small nebula at east end of dark lane
169.....	21 53 38	+58 25	Elliptical black ring; diam. 1°
170.....	21 51 50	+58 22	Irregular black strip 26′ long northeast and southwest
171.....	21 57 43	+58 16	Irregular broken region; diam. 19′
172.....	22 2 43	+58 36	Irregular dark spot
173.....	22 2 53	+59 4	Diam. 4′; rather definite
174.....	22 3 8	+58 28	Narrow; irreg.; 19′ long northeast and southwest
175.....	22 11	+69 19	Large; diam. 1°; bright nebula in north part

No.

13 Irregularly darker inside with a rather sharp, short, narrow extension toward the south.

14 A bright spot in the dark nebula No. 22.

15 See description on page 4.

20 This is the dark object mentioned by Espin in *M.N.*, **58**, 334, 1898. It is close north of a small group of faint stars and is 6′ or 8′ in diameter. In a somewhat larger vacant space. It is not so definite as No. 15.

22 This is a very large region of obscure nebulosity with several darker streaks in it trending northwest. It is partly separated from another starless region lying about 2° to the west and north. Near the middle of the first of these regions is a small luminous nebula with a faint fan-shaped extension for 10′ to the northeast. This is undoubtedly a brighter condensation of the great obscuring mass surrounding it. The position of this small nebula is: $\alpha = 4^h32^m13^s$, $\delta = +25°30'.7$.

25 This is a good example of a dark or more or less starless region.

26 Nos. 26, 27, and 28 are close northwest of B.D. +30°741 ($6^M.8$). (This star is involved in feeble nebulosity.)

30 There is a nebulous border, ½° wide, to the semi-vacant region extending 1° east and north from B.D. +12°803 ($7^M.0$). Apparently this nebulous border extends many degrees east in a very diffused manner. There is a narrow dark lane extending south from the semi-vacant region, running close west of B.D. +12°803 to a point nearly 1° due south of B.D. +12°801 ($6^M.9$). There is a small fan-shaped nebula close north of a small star in the position $\alpha = 5^h24^m30^s$, $\delta = +12°3'.9$. A small strip of nebulosity extends 5′ southwest from this small star. These two nebulae are probably the brighter parts of a large obscure nebulosity.

33 See *Astrophysical Journal*, **38**, 496, 1913, Plate XX.

35 This has an extension to the southeast. There are three small stars north of it.

37 This region is abruptly terminated on the south side by the nebulosity extending north from 15 Monocerotis. Its west side ends abruptly in $\alpha = 6^h22^m15^s$, $\delta = +12°26'$.

39 A small elongated spot in the nebulosity from 15 Monocerotis.

40 This spot and No. 41 are connected with the great nebula about Nu Scorpii and are doubtless denser opaque masses of the nebula. There is a larger dark region belonging to this same system in $\alpha = 16^h23^m$, $\delta = -19°30'$ (No. 43), from which broken dark lanes somewhat like those from Rho Ophiuchi, though less marked, run eastward for some degrees.

42 This object is put in the list because, though not wholly dark, it is partly so, and the evident obscuration produced by it puts it in the class for which the catalogue is made. The semi-vacant region in which this, the great nebula of Rho Ophiuchi, lies is about 3½° in diameter.

44 This is the middle of the main part of the great vacant lane that runs east from the region of Rho Ophiuchi. It is about 32′ wide and has its

No.

beginning in a vacant area in which is the star C.D. $-24°12695$ ($5^{M}.5$), $\alpha = 16^{h}22^{m}38^{s}$, $\delta = -24°51'$. It runs slightly northeast to about $\alpha = 16^{h}40^{m}$, $\delta = -23°40'$. From this point it extends in a broken chain of dark spots to a little south of No. 63. Its total length is therefore about 10°.

44*a* This appears to be a real, dark object.

45 Extended northeast and southwest with an irregular projection southwest that connects it with the Rho Ophiuchi region. This appears to be a real, dark object.

46 A string of small stars in the middle.

47 Connected with No. 51 by two sharp lanes.

48 Extended northeast and southwest. Close west and north of C.D. $-40°11088$ ($8^{M}.0$). This seems to be a real object.

50 This is an irregular square 15′ in diameter, sharply defined on the east side and diffused on the west, where there are broken extensions for ½°. The star C.D. $-34°11418$ ($9^{M}.8$) is near the middle. The stars C.D. $-34°11422$ ($9^{M}.8$), $-34°11426$ ($9^{M}.8$), and $-34°11427$ ($9^{M}.9$) are on the eastern border.

51 Two straggling dark lanes run west to No. 47.

52 One of a straggling group toward the eastern end of the dark lane from Rho Ophiuchi.

55 C.D. $-31°13582$ ($8^{M}.9$) near the center.

56 Close east of C.D. $-31°13609$ ($9^{M}.0$) and $-31°13618$ ($9^{M}.3$). This seems to be a real object.

59 At the west end of a wide broken lane from No. 78.

60 This and No. 57 are the most distinct of a group of dark spots southwest of the square end of No. 63.

62 This seems to be a real object.

63 This is the center of a great curved figure convex to the north 1°37′ long and 19′ wide. See description of Plate III.

64 See description of Plate IV.

72 This is a striking object. It is a thin, curved black marking, the exact form of the letter *s* or the figure 5, as the imagination or point of view may dictate. The southeast branch runs east for some distance passing close south of the star C.D. $-23°13370$ ($9^{M}.9$). Its average thickness is about 2′ to 3′. The position in the catalogue is for the southern part of the figure, or the bottom of the *s*. See Plate III.

74 Slightly curved, extending 5′ north from the star C.D. $-24°13325$ ($7^{M}.1$). It is sharpest on the west and south sides.

75 B.D. $-21°4598$ on the north edge. See description of Plate II.

76 This is a broken, black strip, ½° long, extending east and west.

77 Connected by a vacant strip with No. 78.

78 C.D. $-26°12152$ ($6^{M}.2$) is south of the middle.

80 Close southeast of B.D. $-21°4674$ ($8^{M}.1$).

81 Close southwest of N.G.C. 6401.

No.

82 8′ north of N.G.C. 6401.

83 Narrow extension to the south. Several small stars in it.

84 See description of Plate II.

84*a* B.D. −19°9457 ($9^{M}5$) in the center.

85 This is the southern part of the Trifid Nebula, N.G.C. 6514. The dark markings in this nebula are too well known to insert in this catalogue.

86 There is a small cluster close east of this spot. See page 3.

88 There are other well-known markings in this nebula. This one and No. 89 are given as illustrations of dark markings in the sky shown in relief against a nebulous or other luminous background. In this case these may be non-luminous opaque parts of the nebula itself.

90 There are many similar dark spots in this region, but this one is perhaps the most distinct and is fairly characteristic of the others.

91 This is a round, sharply defined, dark bay in the east side of a very diffused nebulosity which extends east from M 8. Photographs on July 26 and 27, 1905, show the planet Uranus in this bay. It was nearly central in the bay on July 27.

92 This black spot is very sharply defined on its east edge but less definite on the west. There is a twelfth magnitude star near the middle with several other small stars. See *Astrophysical Journal*, **38**, 496, 1913, Plate XX, for an account of this remarkable object.

93 This object has a sharply defined black head 2′ in diameter with a diffused tail 15′ long running south. See Plate XX, as in last note.

98 See description of Plate IV.

99 The east end is the larger with a faint star in it.

100 Larger at east end; diameter 12′. There is a small star in the southeast edge.

101 Separated from No. 100 by a scattering of small stars.

103 Apparently a real object, the south of several dark markings covering a space 45′ in diameter. They form a notched outline to the northwest side of the large star-cloud in Scutum.

104 This consists of a narrow straight black line 16′ long north and south, with a narrow spur at the south end extending west and north for 5′. The width of these lines is about 0′.7.

108 This object is not black. There are two narrow diverging lanes extending to the north. Some small stars in it.

110 Free of stars. A small star near the west edge.

111 See page 6 for description.

112 Perhaps due to want of stars.

115 Very narrow, running north and south for 7′; width 1′.4. It is in a small vacant region.

117 This is on the border of a larger dark region with dark lanes running to the north and northeast. It is separated from No. 118 by several very small stars.

No.

118 More definite and blacker than No. 117.

119*a* This is liberally sprinkled with stars in its northwest half. There are several narrow dark lanes in its southeast portion.

120 The east side is bounded by a curve of very small stars.

122 Round, small, and black. The entire object is fairly well defined and uniformly dark. There is a small star 4′ to the northeast.

123 This has a narrow spur 4′–5′ long from its northeast edge, and a narrow lane 18′ long and 1½′ wide from its west side to the northwest.

125 Fairly well defined on the north border. Some faint stars in it.

126 An irregular narrow dark streak extends 9′ to the northeast; another from its south side runs close to B.D. −4°4650 ($7^{M}.4$). A small star in the northeast edge.

127 Very black in its southeast portion, diffused on the west side. A short line of faint stars on its west edge.

128 A narrow extension 13′ long from the northeast side. A small star close west of it. This is in a larger vacant region.

129 Very black, sharply defined, with a considerable small star at the west end. Somewhat rectangular in form with projections to the east. It is the blacker western portion of a dark region 10′ in diameter. Nos. 127, 129, and 130 are connected in an irregular curve convex to the west.

131*a* This is a very small black spot with a small star on the north border and another on the south, with a fine curve of six or seven very small stars running northwest from its north edge.

132 Tadpole-shaped with B.D. −4°4680 ($9^{M}.0$) in center of the larger (west) part. Length east and west 16′.

133 This object begins very close west of B.D. −7°4852 ($9^{M}.2$). From this it gradually widens and curves north like a plume, with the convex side west, to a distance of about 18′. The south end is intensely black. The northern part is dark with 4 or 5 considerable (small) stars in it. See description of Plate IV.

134 This is dark, but not sharply defined. There is a small star on the south edge and a similar one on the north edge.

135 The star B.D. −4°4698 ($9^{M}.2$) is on the north border and B.D. −4°4702 ($9^{M}.2$) on the southeast border.

138 Perhaps the most striking feature of this great curved "lane" is the definiteness of its eastern outline. To the west it is less definite and in the lower, south, half it consists of dark branching structures which blend into a part of the Milky Way relatively dimmer than that to the east. The stars embraced by the curve to the east are much brighter or coarser than those to the west. If the stars to the west were fewer in number, or fainter, the eastern outline would closely resemble the great head of the star-cloud near M 11 in Scutum. The southern termination is in a small, comet-shaped, very black spot, apparently a real object, sharply defined on its south edge.

No.

139 This spot is the beginning of a great curved lane ending in about $\alpha = 19^h14^m$, $\delta = +1\frac{1}{2}°$. This lane is concave to the east, on which side it is more definite.

143 The outline of a square $\frac{1}{2}°$ in diameter, with the west side missing.

144 See page 10.

145 This is a triangular semi-vacant area. It is covered by a sprinkling of considerable small stars with the star B.D. $+37°3736$ ($9^M.5$) in the center.

146 This spot is like a dark border to the southwest side of the star B.D. $+35°3930$ ($7^M.0$).

150 This is the center of the dark marking. Its head is in the position $\alpha = 20^h51^m0^s$, $\delta = +59°45'$. The west end or tail is in $\alpha = 20^h43^m50^s$, $\delta = +49°20'$. This object is fully described in the text.

151 This appears to be a real object in a slightly larger vacancy.

152 Close north of B.D. $+61°2103$ ($8^M.9$). See *Astrophysical Journal*, **43**, 1, 1916. It is there wrongly stated that the object is south of the B.D. star. The west end is larger with a small star in it.

154 The star B.D. $+55°2565$ ($7^M.4$) is at the south end.

155 There are four small stars in a line crossing this object east and west.

156 The star B.D. $+44°3865$ ($4^M.1$) is central.

157 A semicircle of faint stars forms the western border.

158 This spot is similar to those in the region of No. 159. There are some others north and west of this.

159 This is the center of an irregular, partially vacant region 25′ in diameter. It is suggestive of the presence of a dark or faint nebulosity, as there are several small darker spots in it. It lies 40′ northwest of Nova Cygni of 1876, and involves the stars B.D. $+42°4177$ ($5^M.2$), $+42°4172$ ($8^M.4$) and $+42°4164$ ($7^M.7$). It is somewhat extended east and west. A very long exposure on this region would doubtless be interesting.

160 The east side is best defined with two dark projections from it 30′ apart. An irregular, narrow, dark lane runs north from it for 2° to a large nebulous region.

161 This is one of the comet-shaped objects. The head is very sharp and black, 3′ across. This extends north for some 3′, then widens out into a less dense tail about 13′ long.

162 A curve of small stars on the southwest end.

163 There are two dark streams running from this to the north.

165 B.D. $+59°2424$ ($7^M.8$) is on the north edge and B.D. $+59°2427$ ($7^M.7$) near the southeast end.

168 This nebula is 10′ in diameter with over a dozen small stars of different magnitudes in it. There is no central condensation, nor does the nebula condense about any of the stars. There are some dark markings in it. The dark lane is 1°.7 long and 9′ wide. See *Lick Observatory Publications*, **11**, Plate 81.

No.

169 This incloses an island of small stars. The dark ring is broadest on its east side where its thickness is 22′. The northern part is very black and straight.

170 This is the northwest border of the island of small stars. It is sharply defined and darker than the sky.

171 This is at the east end of the island of small stars.

173 There is a small star on the north edge and also one on the southwest edge.

175 This is a large dark spot, extended north and south, 62′ in its largest diameter. In its upper part is the star B.D. +69°1231 ($8^{M}8$) which is nebulous. This is apparently a large dark nebula, the brighter part of which forms the star +69°1231. In *Monthly Notices*, **69** (December) 1908, Dr. Max Wolf gives a photograph of the nebula, stating that the object was discovered by Dr. Kopff at Heidelberg on October 12, 1908. It is conspicuous on a photograph of mine made with the Willard lens at the Lick Observatory, September 24, 1895, with $5^{h}0^{m}$ exposure. It is also shown on a photograph of mine made with the Bruce telescope, July 20, 1904, with an exposure of $3^{h}1^{m}$. By inadvertence reference to this object was omitted in *Lick Observatory Publications*, **11**, where it is cut out by the matting in Plate 83.

I am greatly indebted to Miss Mary R. Calvert for invaluable aid in the preparation of this catalogue.

YERKES OBSERVATORY, WILLIAMS BAY, WIS.
December 10, 1918

STUDIES BASED ON THE COLORS AND MAGNITUDES IN STELLAR CLUSTERS[1]

NINTH PAPER: THREE NOTES ON CEPHEID VARIATION

By HARLOW SHAPLEY

At least three classes of stars may be independently used to ascertain the distances of globular clusters through luminosity correlations—Cepheid variables, B-type stars, and the giants of the redder spectral classes. The giant red stars in local parts of the galactic system, as well as in globular clusters, are now known to have a limited dispersion of absolute luminosity; and if we should assume the absolute magnitude in the mean to be the same in both regions, it is readily shown that the resulting parallaxes of the clusters would be closely comparable with the values obtained in the present investigation.[2] The stars of spectral type B (color-class *b*) form a second class of objects that are generally recognized as valuable criteria of distance, not only because of a fairly small dispersion of intrinsic brightness, but also because much is known of the actual absolute magnitudes through studies of community motion and parallactic drift. Apparently, however, there is a tendency for B-type stars to fall into groups that may differ in real brightness by one or two magnitudes,[3] thus introducing a large percentage of uncertainty into the distances depending on magnitude correlations. If, as seems necessary from related investigations, the most luminous *b*-class stars in clusters are equated in luminosity with the galactic B stars that have an average absolute magnitude near zero, the distances of globular clusters (and of all Cepheids) are essentially as now adopted. On the other hand, if the brightest *b*-class stars

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 154.

[2] For example, see Division III of the parallax determinations of Messier 13 listed in Table XXVII of *Mt. Wilson Contr.*, No. 116, 1915. The parallax there derived from red giants is 0".00010; that now adopted is 0".00009. Applying this method we would readily obtain also the absolute magnitudes of all Cepheids, and then derive practically the same individual parallaxes for them as given in the eighth paper.

[3] Kapteyn, *Mt. Wilson Contr.*, No. 82, 1914; Charlier, *Meddelanden från Lunds Astronomiska Observatorium*, Series 2, No. 14, 1916.

are equated in luminosity with the most luminous of galactic B's, or if much weight be placed upon a direct application of the fragmentary luminosity-curves of B stars,[1] the distances and all the dependent dimensions would be considerably greater, and all giant red stars and Cepheid variables would be systematically much brighter in clusters than in the general galactic system.

The present study has shown that for the third class of bright stars common to clusters and the general system—the Cepheid variables—the luminosity is simply a function of the period of light-variation, and, except for some uncertainty in the zero-point of the absolute scale, may be very accurately known. In consequence the Cepheids become of so much greater weight in the estimation of the parallaxes of globular clusters that other classes of highly luminous stars can best be used only to check the results, or as secondary standards.[2]

Although the distances obtained independently of the Cepheids would, as suggested above, be much the same as we have found, and the same conclusions as to the size and structure of the general system of clusters would result, the computed certainty of the distances and dimensions would be of a much lower order. The adopted numerical values therefore depend mainly upon the Cepheid variables, and the investigation of all phenomena related to the luminosity of these stars becomes appropriate. In particular it is important to see if there is any evidence that the variables of a given period in different systems are unlike in median magnitude. In the present communication three notes are brought together that bear on the question of Cepheid variation.

I. THE RELATION OF PERIOD TO LUMINOSITY

In the second and third sections of the sixth paper of this series we have determined a very definite observational relation between the period of light-variation of a Cepheid variable and its

[1] *Mt. Wilson Contr.*, No. 116, p. 81, 1915; cf. also Eddington, *Monthly Notices*, 77, 608, 1917.

[2] Through the method of measuring distance by means of the "25 brightest" stars, the red giants have been used in the rôle of secondary standards to determine the parallaxes of nearly all the clusters of Table V in the seventh paper.

total light emission. The luminosity-period curve, based on observations from seven different stellar systems, is reproduced in the lower part of Fig. 1, where absolute magnitude is plotted against the logarithm of the period in days. The curve is defined by more than 330 stars, of which nearly 40, having periods longer than a day, fall along the curve at points where the variation of magnitude

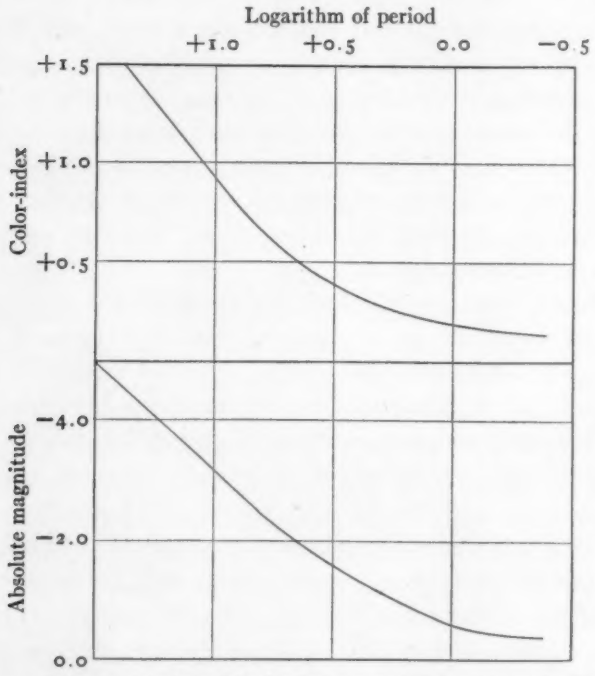


FIG. 1.—*Above:* Relation of period to color-index for Cepheid variables. *Below:* Relation of period to median absolute magnitude for Cepheid variables.

with period is rapid. Considering the uncertainties in the periods and magnitudes for some of the stars, the average deviation from the smooth curve is remarkably small—there is hardly a Cepheid known to be discordant.

From the curve we see first that the decrease of median brightness with decreasing period is essentially linear until a period of less than three days is reached, and second that the absolute magnitude decreases no farther after the period has become a little

shorter than one day. Referring to another curve in the same paper, which is reproduced in the upper part of Fig. 1, we observe that the change of median color-index with period is of much the same general character. A few remarks may be made on the possible interpretation of these curves.

It has been shown in an earlier paper[1] that the relation of period to spectral type and color-index can be provisionally explained (if we adopt a pulsation hypothesis of Cepheid variation) as a result of increasing density with decreasing color-index for giant stars. Thus a general relation, which is known to have a wide application in astronomical and physical problems and which holds without doubt in the present case, gives the period, P, of an oscillation in a gaseous star as a function of the radius and the surface gravity; or, if $\bar{\rho}$ is the mean density,

$$P^2 \propto \frac{1}{\bar{\rho}} \tag{1}$$

For giant stars the dependence of mean density on spectrum is approximately known from eclipsing binaries, and the application of (1) to Cepheid variables of known period gives for each spectral type a mean density of quite the same order as that found from eclipsing stars. Thus, through the intermediary of the mean density, the observed connection of median color-index and period is readily understood.

The reason for the dependence of luminosity on period is not so definite, but the following discussion seems to indicate the physical interpretation. If L be the total luminosity of a giant star, we may write[2]

$$L = \pi r^2 J$$

where r is the radius and J the luminosity per unit of apparent surface. Now $J = f(T, \rho_s, i)$; that is, the light intensity per unit area depends, not only upon the effective surface temperature, T, but probably also upon the density at the stellar surface, ρ_s, and the degree of ionization, i—the last involving, it may be, the chemistry of the star as well as its ordinary physical properties. But with

[1] *Mt. Wilson Contr.*, No. 92; *Astrophysical Journal*, 40, 448, 1914.

[2] Neglecting darkening at the limb.

good cause we believe that the effective temperature (and hence the color-index, C.I.) is by far the most important factor in surface brightness. Denoting mass by μ, we may write

$$L \propto r^2 f_1(T) \propto \left(\frac{\mu}{\bar{\rho}}\right)^{\frac{1}{3}} \phi(\text{C.I.}).$$

Introducing (1),

$$L \propto (\mu P^2)^{\frac{1}{3}} \phi(\text{C.I.}) \qquad (2)$$

and we have a physical explanation of the interdependence of the luminosity and period in Cepheid variation.

For the absolute magnitude, M, of stars differing little in spectral type (such as the Cepheid variables for which proper motions are known) we derive from (2)

$$M \propto 2 \log P + \log \mu.$$

It appears from Eddington's theoretical work on giant stars as well as from observational data relative to binaries of various types that the range in the masses of stars is small, so that the approximate theoretical relation

$$M = k \log P \qquad (3)$$

is of the same form as that observed for the Cepheid stars of longer period (Fig. 1).

The inclusion of $\log \mu$ in (3) would not in the mean disturb the linear form of the relation, for the dispersion in mass is, so far as we know, comparable for giants of different spectral types redder than A. But over a wide range of spectrum ϕ (C.I.) becomes important in maintaining the luminosity in the face of contraction. The increase of surface intensity, with the progression toward bluer spectrum, may wholly counterbalance the tendency to diminish the total light-emission through shortening periods and smaller stars—especially near the blue end of the giant series where critical and asymptotic conditions are more likely to prevail[1]—and in consequence the luminosity-period curve theoretically should flatten out

[1] "The concurrent progression toward a definite limit of luminosity, spectrum, and period suggests that, in the evolutionary sequence of stars, Cepheid variation is abruptly limited at or near the blue end of the giant series because of the changing physical conditions in the interiors of the gaseous masses."—*Mt. Wilson Contr.*, No. 151, p. 21, 1917.

as observed. If, however, the counterbalance is maintained throughout the whole giant series and luminosity depends only on the mass, as some important researches suggest,[1] then (1) the mass apparently determines when in a star's history Cepheid variation may occur, (2) the period never changes materially during the life of the variation except possibly for cluster-type variables, and (3) the luminosity-period law may more appropriately express the mass-period or mass-density relation of Cepheid variation.

It appears from the foregoing consideration that, granting the pulsation hypothesis of Cepheid variation, there is a definite reason for the dependence of total luminosity on period and a fairly plausible interpretation of the almost linear relation between the logarithm of the period and absolute magnitude. Quantitative evaluation of the theoretical equations should be possible eventually, and in fact has already been made tentatively. The computed results roughly conform with observation, but little weight can be attached to this agreement because of the present necessity of rather vague assumptions as to the progression, with spectral type, both of J and of darkening at the limb.

Eliminating the logarithm of the period from the two curves of Fig. 1, we obtain in Fig. 2, in the plot of absolute magnitude as a function of color-index, a curve that may be of considerable importance in Cepheid theories. For comparison with this curve the relation between absolute magnitude and color-index for the giant stars in four globular clusters is plotted along a broken line in the same figure.[2] We note that the change of luminosity with advancing spectral type is about the same for Cepheid variables of the galactic system as for all giant stars of globular clusters. Perhaps our more extensive knowledge of the former can throw light on the general problem of the relationship of successive spectral types.

The constant difference between the curves of Fig. 2, which is certainly larger than any systematic error involved, indicates that for a given color Cepheids are more than twice as bright as other

[1] Various papers by Eddington and Jeans in the *Monthly Notices*, *Nature*, and *The Observatory* during 1916 and 1917. Cf. the tenth paper of this series, p. 8.

[2] Adapted from the mean of the results given in Table II of *Mt. Wilson Communications*, No. 34; *Proceedings of the National Academy of Sciences*, 2, 525, 1916.

stars; or rather, since the largest uncertainty is probably in the colors of the Cepheids, it indicates that for a given magnitude the variables appear to be nearly 0.4 mag. bluer than other giant stars. If minimum color and magnitude of the Cepheids be substituted for the median values, the two curves become nearly coincident.

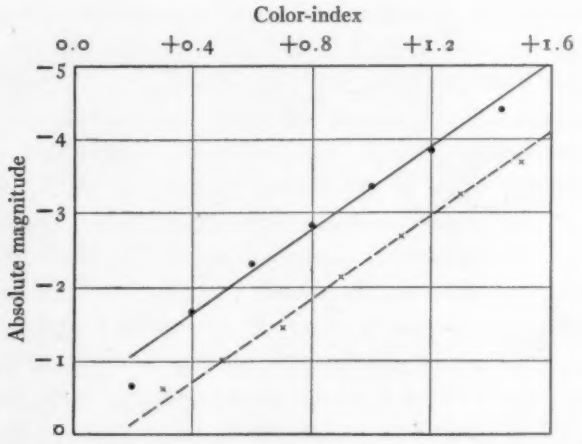


FIG. 2.—Relation of color-index to absolute magnitude for Cepheid variables. The broken line represents the corresponding relation for the giant stars of Messier 3, 5, 13, and 15.

II. THE COMPOSITE COLOR-CURVE OF 103 CLUSTER-TYPE VARIABLES

The determination, from plates made with the 60-inch reflector, of the magnitudes of a sequence of reference stars in Messier 3, permits the transformation to the Mount Wilson system of the light-curves derived by Bailey.[1] Since details of the derivation of magnitudes for the comparison stars will appear elsewhere, it will suffice for the present note to give only the final photographic and photo-visual results. The first two columns of Table I contain the designation of the comparison star by Bailey and the corresponding number in von Zeipel's catalogue.[2] The Harvard and Mount Wilson photographic magnitudes, in the following columns, differ in part because of the well-known systematic difference between

[1] *Harvard Annals*, **78**, Part 1, 1913.

[2] *Annales de l'Observatoire de Paris*, **25**, 1, 1908.

the two systems, but mainly because of the somewhat provisional nature of the published Harvard magnitudes for this sequence of stars.[1] By plotting against each other the numbers of the third and fourth columns a fairly smooth curve is obtained which can be used to change the observed photographic magnitudes from one system to the other.

TABLE I

COMPARISON STARS IN MESSIER 3

DESIGNATION		HARVARD PHOTOGRAPHIC MAGNITUDE	MT. WILSON PHOTOGRAPHIC MAGNITUDE	MT. WILSON PHOTO-VISUAL MAGNITUDE	COLOR-INDEX
Harvard	von Zeipel				
a	740	13.50	14.10	13.40	$+0^{M}.70$
b*	238	13.58	14.27	12.48	+1.79
c	640	13.98	14.40	13.22	+1.18
d	263	14.22	14.53	13.41	+1.12
e	250	14.50	14.81	13.91	+0.90
f	218	14.98	15.04	14.51	+0.53
g	227	15.28	15.25	14.60	+0.65
h	258	15.70	15.52	15.54	−0.02
k	609	16.00	15.66	15.70	−0.04
l	1131	16.23	15.81	15.48	+0.33
m	1055	16.49	15.95	15.26	+0.69
n	1327	16.82	16.17	15.49	+0.68
o	.....	17.15	16.43	15.78	+0.65
p	.....	17.63	16.79	16.38	+0.41

* Variability suspected by Bailey.

The close similarity of the photographic light-curves of the typical variables in Messier 3 makes possible the general representation of them all by the single mean curve[2] which is tabulated in the first two columns of Table III and drawn as a full line in Fig. 3. Whatever irregularities may exist in the individual variations are smoothed out, of course, in this mean; and in particular the range may be slightly too small because the rapid variation at maximum is concealed to some extent by the length of exposures necessary on the Harvard plates. Also it is not likely, except in the mean curve, that the light actually remains constant for three hours at minimum. It is to be noted in this mean result, however, that both the form

[1] Cf. *Mt. Wilson Contr.*, No. 115, p. 13, n. 1. In a recent letter Professor Bailey writes that the magnitudes are being revised on the basis of the Harvard Polar Sequence.

[2] Derived from Bailey's Table XIX, *op. cit.*, p. 89.

of the curve and the photographic amplitude of 1.2 magnitudes are much the same as those usually observed for isolated cluster-type variables.

The derivation of visual or photo-visual curves for each of these variables would entail much work, but a mean photo-visual curve can be derived with considerable certainty and without difficulty through the determination of a composite color-curve. Making use of the remarkable similarity of the variables and noting that the slightly differing periods are not commensurable, we may, if we

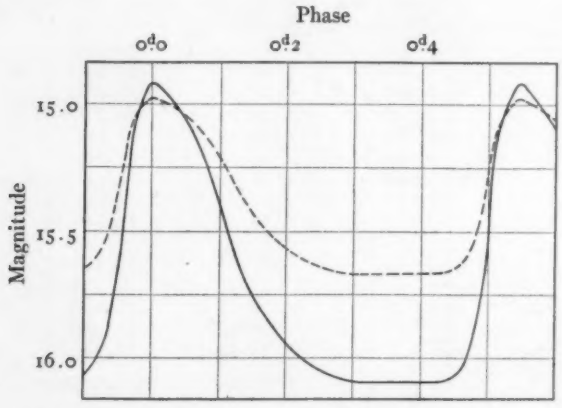


FIG. 3.—Mean photographic and photo-visual light-curves of 103 cluster-type variables in Messier 3.

choose, interpret the hundred magnitudes which are derived for variable stars from a single photograph of the cluster as a hundred different observations distributed at random along the light-curve of one variable—that is, along the mean light-curve. Similarly, the determination of the color at a given instant for the hundred variables gives immediately a hundred observations for the determination of a mean color-curve. Some of the periods, however, are not known accurately enough to allow the computation of phases for the time of observation, and the curve, therefore, gives color as a function of photographic magnitude rather than of time. To distinguish this property it will be called a composite color-curve.

For the measures of color, two pairs of photographs of Messier 3 were made on December 20, 1917, each pair consisting of a

TABLE II

Variable	Plates 4309 and 4310		Plates 4311 and 4312	
	Photographic Magnitude	Color-Index	Photographic Magnitude	Color-Index
173	15.06	$-0^{M}15$	14.68	$-0^{M}37$
181	16.33	.....	16.30	+0.18
214	15.54	−0.01	15.68	+0.08
221	16.28	+0.36	16.34	+0.47
222	15.91	+0.19	15.68	+0.37
223	15.41	+0.29	15.54	+0.21
226	15.70	+0.06	15.92	+0.19
234	15.70	+0.35	15.87	+0.47
249	15.06	+0.03	15.64	+0.39
252	15.70	+0.12	15.95	+0.27
253	15.77	+0.44	15.51	+0.17
264	16.23	+0.44	16.24	+0.23
278	15.20	+0.08	15.39	+0.12
279	15.77	+0.22	15.95	+0.52
296	15.33	+0.17	15.61	+0.39
305	15.70	+0.28	15.95	+0.52
318	13.95	+1.61	13.88	+1.52
321	16.20	+0.43	16.05	+0.24
328	15.91	+0.22	15.99	+0.52
338	15.20	−0.08	15.39	+0.05
351	15.87	+0.29	15.97	+0.36
353	15.65	+0.21	15.61	+0.21
355	15.49	+0.32	15.47	+0.34
361	16.20	+0.38	16.12	+0.38
362	15.83	+0.39	15.86	+0.39
366	15.91	+0.33	15.51	+0.36
374	15.14	+0.21	15.34	+0.12
378	16.24	+0.42	16.05	+0.15
379	15.61	+0.32	15.68	+0.25
384	14.47	−0.29	14.83	−0.09
391	16.20	.....	16.18	+0.38
396	15.91	+0.22	16.09	+0.29
397	15.94	+0.31	16.09	+0.75
404	16.46	+0.64	16.03	+0.53
411	16.20	+0.46	16.09	+0.35
425	15.98	+0.34	16.09	+0.59
451	15.41	+0.20	15.64	+0.30
455	15.77	+0.01	15.84	+0.17
479	15.36	+0.20	15.61	+0.30
537	15.93	+0.43	16.12	+0.50
541	14.88	+0.14	15.08	−0.05
616	14.62	−0.16	15.01	+0.09
623	14.97	−0.03	15.34	+0.18
644	16.35	+0.53	16.05	+0.55
650	15.91	+0.06	16.03	+0.08
656	14.97	−0.16	15.61	+0.34
679	15.41	+0.25	15.68	+0.22
700	15.91	+0.24	15.92	+0.42
710	16.46	+0.72	16.34	+0.49
713	16.20	+0.67	15.87	+0.13
759	16.28	+0.59	16.13	+0.63
765	15.14	+0.21	15.61	+0.40

TABLE II—*Continued*

Variable	Plates 4309 and 4310		Plates 4311 and 4312	
	Photographic Magnitude	Color-Index	Photographic Magnitude	Color-Index
775.....	16.33	+0^{M}66	16.23	+0^{M}37
776.....	15.40	+0.22	15.68	+0.25
818.....	15.21	+0.27	15.25	+0.22
840.....	15.91	+0.09	16.10	+0.44
873.....	15.14	+0.14	15.44	+0.26
922.....	15.77	+0.27	15.83	+0.37
948.....	15.91	+0.56	15.08	+0.16
965.....	15.91	+0.33	16.05	+0.50
999.....	15.70	+0.33	15.92	+0.34
1003.....	15.55	+0.38	15.54	+0.32
1041.....	16.26	+0.62	16.06	+0.21
1057.....	15.91	+0.28	16.05	+0.40
1090.....	15.91	+0.63	15.94	+0.48
1105.....	15.87	+0.37	15.97	+0.49
1122.....	15.94	+0.48	16.09	+0.59
1126.....	15.33	+0.41	15.28	+0.12
1164.....	16.38	+0.66	16.12	+0.36
1181.....	16.28	+0.44	16.24	+0.41
1184.....	15.06	+0.02	15.34	+0.04
1187.....	15.66	+0.38	15.68	+0.35
1201.....	16.09	+0.46	16.23	+0.49
1202.....	15.26	+0.15	15.61	+0.27
1207.....	15.05	+0.12	15.39	+0.26
1222.....	15.77	+0.56	15.54	+0.27
1231.....	15.91	+0.22	16.09	+0.55
1234.....	15.55	+0.22	15.73	+0.39
1250.....	14.90	+0.16	15.08	+0.12
1253.....	15.91	+0.63	15.92	+0.44
1259.....	15.11	−0.07	15.73	+0.27
1265.....	15.11	+0.07	15.28	+0.15
1268.....	15.70	+0.27	15.01	−0.15
1277.....	15.87	+0.11	16.05	+0.20
1291.....	15.83	+0.20	15.92	+0.44
1292.....	15.91	+0.47	15.50	+0.56
1298.....	15.02	+0.10	15.21	+0.08
1307.....	15.83	+0.62	16.03	+0.57
1308.....	15.91	+0.28	16.05	+0.19
1317.....	15.33	+0.20	15.24	−0.10
1320.....	15.87	+0.20	15.76	+0.30
1321.....	15.70	+0.13	15.87	+0.24
1330.....	15.66	+0.34	15.76	+0.33
1353.....	15.87	+0.24	16.06	+0.30
1357.....	15.83	+0.39	16.05	+0.32
1373.....	15.14	+0.07	15.39	+0.23
1380.....	15.98	+0.31	15.73	+0.13
1384.....	15.41	+0.09	15.61	+0.34
1386.....	15.91	+0.26	15.97	+0.12
1388.....	15.40	+0.08	15.76	+0.42
1400.....	15.60	+0.18	15.92	+0.52
1406.....	15.41	+0.08	15.64	+0.37
1409.....	16.26	+0.74	16.23	+0.17
1422.....	15.10	−0.06	15.47	+0.25

photographic and a photo-visual plate. The photo-visual plates were interrupted when half exposed to obtain the photographic exposures, thus insuring the essential coincidence of the mean times of the two observations. Very rarely will an observation occur at such a phase of the light-variation that appreciable error in the color can arise from this method of observing. The results of the measures are given separately for the two pairs of plates in Table II. The first column contains the number of each variable in von Zeipel's general catalogue, the second and fourth contain its observed photographic magnitude on the Mount Wilson system, and the third and fifth the difference between this magnitude and the corresponding photo-visual result. No. 318, a bright variable to which no type or period has been assigned, is not included in the discussion.

A noticeable diversity of color for a given magnitude is evident in the plots of the individual results of Table II. This may be attributed to accidental error, or to real differences in the variables, or perhaps to actual differences in the color for a given magnitude on the ascending and descending branches. But taking the mean of the color-indices, grouped in order of photographic magnitude, a very definite composite color-curve is obtained for each pair of plates. As no material difference appears in the results from the two pairs, the normals for each are combined into the following means, which are graphically shown in Fig. 4:

Mean Photographic Magnitude	Number of Variables	Mean Color-Index
14.78	7	−0.14
15.11	23	+0.05
15.38	26	+0.19
15.64	39	+0.27
15.89	58	+0.34
16.12	38	+0.41
16.33	13	+0.55

From the mean photographic curve and this composite color-curve we obtain immediately for the variables of Messier 3 a mean photo-visual curve. The co-ordinates appear in the first and fourth

columns of Table III, and are plotted as a broken line in Fig. 3. Again the form of the curve, its amplitude, and the color variation

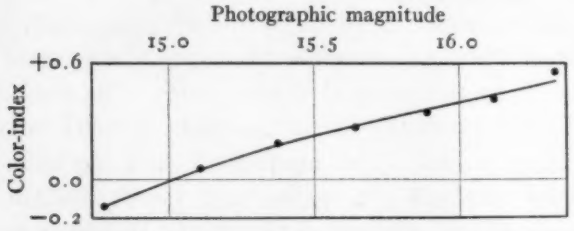


FIG. 4.—Composite color-curve of 103 cluster-type variables in Messier 3

TABLE III

MEAN PHOTOGRAPHIC AND PHOTO-VISUAL LIGHT-CURVES OF CLUSTER-TYPE VARIABLES IN MESSIER 3

Phase	Mt. Wilson Photographic Magnitude	Color-Index	Photo-Visual Magnitude	Phase	Mt. Wilson Photographic Magnitude	Color-Index	Photo-Visual Magnitude
0.000...	14.90	−0^{M}07	14.97	0.271...	16.07	+0^{M}42	15.65
0.011...	14.93	−0.06	14.99	0.283...	16.08	+0.42	15.66
0.023...	14.96	−0.04	15.00	0.294...	16.09	+0.43	15.66
0.034...	15.00	−0.01	15.01	0.305...	16.09	+0.43	15.66
0.045...	15.04	+0.01	15.03	0.317...	16.10	+0.43	15.67
0.057...	15.11	+0.05	15.06	0.328...	16.10	+0.43	15.67
0.068...	15.17	+0.07	15.10	0.339...	16.10	+0.43	15.67
0.079...	15.23	+0.11	15.12	0.350...	16.10	+0.43	15.67
0.090...	15.32	+0.16	15.16	0.362...	16.10	+0.43	15.67
0.102...	15.39	+0.18	15.21	0.373...	16.10	+0.43	15.67
0.113...	15.48	+0.22	15.26	0.384...	16.10	+0.43	15.67
0.124...	15.58	+0.26	15.32	0.396...	16.10	+0.43	15.67
0.136...	15.67	+0.29	15.38	0.407...	16.10	+0.43	15.67
0.147...	15.73	+0.31	15.42	0.418...	16.09	+0.43	15.66
0.158...	15.79	+0.33	15.46	0.430...	16.09	+0.43	15.66
0.170...	15.84	+0.34	15.50	0.441...	16.08	+0.42	15.66
0.181...	15.87	+0.36	15.51	0.452...	16.06	+0.42	15.64
0.192...	15.91	+0.37	15.54	0.464...	16.01	+0.40	15.61
0.204...	15.94	+0.38	15.56	0.475...	15.93	+0.38	15.55
0.215...	15.98	+0.39	15.59	0.486...	15.77	+0.33	15.44
0.226...	16.01	+0.40	15.61	0.497...	15.53	+0.24	15.29
0.237...	16.03	+0.41	15.62	0.509...	15.22	+0.11	15.11
0.249...	16.04	+0.41	15.63	0.520...	15.06	+0.02	15.04
0.260...	16.06	+0.42	15.64	0.531...	14.96	−0.04	15.00

are all sensibly the same as for the isolated cluster-type variables of the galactic system. The quantitative agreement of these distant stars with the local variables in phenomena of color is also

important and favorable evidence of the accuracy of the photovisual and photographic magnitude scales relative to each other, and of the absence of light-scattering in space.

III. ON THE RELATION OF COLOR TO PERIOD FOR CLUSTER-TYPE VARIABLES

In the third and fourth sections of the sixth paper of this series[1] attention has been called to certain properties of the different kinds of cluster-type variables. In ω Centauri, for instance, the three subclasses defined by Bailey differ from each other in the form and amplitude of the mean light-curve, and most clearly in length of period. In Messier 3 and Messier 5, where nearly all variables are of the most typical kind, a second subclass is only sparingly represented, but in Messier 15 the variables fall into two nearly equal groups. It appears definitely that the median intrinsic luminosity in all subclasses is photographically the same—an important phenomenon that a full interpretation of these variables must explain.

The differences in period of the subclasses naturally suggest corresponding differences in the effective density; or it may be that the character of the underlying pulsation differs somewhat in the various groups. On the basis of the first alternative, if the mean densities increase with shortening periods[2] while the photographic magnitudes do not change, we must expect the change in the surface area to be compensated by greater intensity of radiation per unit of surface, and investigations of the color phenomena for the different subclasses should afford a partial test.[3]

In Messier 15 the faintness of the variables makes a detailed study of individual color-curves inadvisable at present, and accordingly the method used in the preceding note is employed to obtain composite color-curves for the two groups of variables. Professor Bailey has kindly communicated, especially for the present investigation, the preliminary results of his study of the periods and light-curves of the 53 variables in this cluster.[4] One or two have periods

[1] *Mt. Wilson Contr.*, No. 151, 1917. [2] See sec. I of this *Contribution*.

[3] ω Centauri is too far south for detailed color investigations at Mount Wilson. Color-curves are being derived for the variables of Messier 5.

[4] A preliminary report on his work is abstracted in *Popular Astronomy*, **25**, 520, 1917.

longer than a day, for several the periods have not yet been found, and for others accurate photometric measures are not possible.

TABLE IV

COMPOSITE COLOR-CURVES OF VARIABLES IN MESSIER 15

VARIABLE	APPROXIMATE PERIOD	PLATES 4284–4285		PLATES 3986–3987	
		Photographic Magnitude	Color-Index	Photographic Magnitude	Violet-Index
2	$0^d.66$	16.13	$+0^M.51$	16.21	$-0^M.10$
3	0.39	16.18	+0.44	15.90	+0.03
4	0.31	16.27	+0.44	15.85	−0.12
5	0.38	15.90	+0.16	16.43	−0.29
6	0.67	16.13	+0.39	16.11	+0.05
7	0.35	16.27	+0.50	15.99	−0.16
8	0.65	15.42	+0.06	16.03	−0.01
9	0.72	15.49	+0.08	16.36	−0.10
10	0.40	16.27	+0.42	16.32	−0.12
11	0.34	16.18	+0.23	16.03	−0.07
12	0.59	16.22	+0.28	16.34	−0.14
13	0.57	16.38	+0.36	16.42	−0.02
14	0.38	16.10	+0.35	16.08	−0.20
15	0.58	16.13	+0.19	16.26	−0.24
16	0.67	15.53	−0.20	15.85	−0.10
18	0.37	15.49	−0.16	15.90	−0.07
19	0.57	16.47	+0.65	16.47	.....
20	0.69?	15.98	+0.33	16.03	−0.19
22	0.72	15.98	+0.26	15.52	+0.13
23	0.67	16.13	+0.36	16.31	.....
24	0.37	16.52	+0.68	15.78	+0.02
25	0.67	16.27	+0.33	16.42	−0.16
26	0.40	16.18	+0.26	16.37	.....
29	0.57	16.10	+0.30	16.37	−0.11
30	0.41	15.56	−0.09	16.03	−0.02
31	0.44	15.90	+0.19	16.58	.....
32	0.61	16.13	+0.31	15.75	−0.08
35	0.38	15.90	+0.19	16.44	−0.28
38	0.38	15.53	−0.23	16.44	−0.20
39	0.39	16.06	+0.32	15.85	−0.10
40	0.38	16.10	+0.33	15.90	+0.02
41	0.42?	16.27	+0.56	16.03	−0.01
42	0.36	15.49	−0.18	16.32	−0.27
43	0.29??	15.66	−0.05	15.96	−0.03
44	0.60	15.82	+0.08	16.35	−0.19
45	0.66	16.30	+0.54	15.96	−0.08
48	0.38	15.56	−0.16	15.82	0.00
50	0.30	16.22	+0.28	16.43	−0.17
51	0.42	16.30	+0.36	16.22	−0.06

The 39 variables with periods less than a day, for which photovisual and photographic magnitudes have been obtained from a pair of plates made on December 19, 1917, are listed in Table IV.

As a preliminary to the derivation of the magnitudes and colors of the third and fourth columns, it was necessary to study the comparison stars by means of a series of polar comparisons. At the same time colors were determined for a considerable number of other stars in the cluster. Since the discussion of magnitudes follows the customary lines, all details may be omitted from this note.

The color-index of each variable is plotted against photographic magnitude in the upper part of Fig. 5, the dots indicating variables with periods between $0^d.57$ and $0^d.71$ and the crosses indicating those

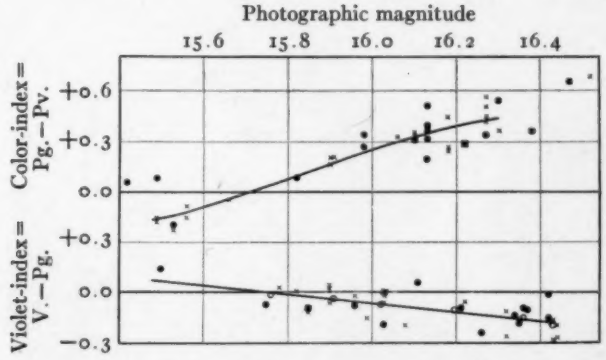


FIG. 5.—Composite color-curves of cluster-type variable stars in Messier 15; the dots refer to the longer-period subclass, crosses to the shorter-period subclass, and open circles to means of six values.

with periods between $0^d.29$ and $0^d.44$. As in the preceding note, all dots may be interpreted as representing different observations on a single mean variable of period about $0^d.64$, and the crosses as representing different observations on a typical variable in the second group, with mean period of about $0^d.36$. The usual absolute values of the color and the usual increase of redness with decreasing brightness are shown by the observations; but no material difference appears in color for the two groups, except, perhaps, near maximum, where there is a suggestion that the stars with longer period are redder.[1]

The test for difference in color has been carried into the region of shorter wave-lengths by a pair of plates made September 11, 1917,

[1] This would be in keeping with results for Cepheids with periods longer than a day. Cf. Fig. 1.

in which, as a companion to an ordinary photographic plate, a photograph was made on a Seed 27 plate through a violet-color screen that transmits very little to the red of λ 4000 and has a maximum transmission at about λ 3700. The results are tabulated in the last two columns of Table IV and plotted in the lower part

TABLE V

RELATION OF VIOLET-INDEX TO COLOR-INDEX FOR GIANT STARS IN MESSIER 15

Star	Photographic Magnitude	Color-Index (Pg.−Pv.)	Violet-Index (V.−Pg.)
a	14.14	$+1^{M}.32$	$+0^{M}.70$
b	14.51	+0.79	+0.15
c	14.58	+1.18	+0.42
d	14.81	+1.18	+0.33
e	14.76	+1.06	+0.46
f	14.98	+1.04	+0.14
g	15.01	+0.75	+0.13
h	15.23	+0.93	+0.28
k	15.49	+0.70	+0.16
l	15.68	+0.68	−0.03
m	15.97	+0.29	+0.01
n	16.02	+0.21	0.00
t	16.10	+0.18	−0.05
u	16.60	+0.66	−0.06
x	16.05	+0.64	0.00
y	14.51	+1.23	+0.55
z	15.07	+0.08	−0.09
100	14.17	+1.40	+0.78
103	13.09	+0.45	+0.36
104	14.11	+0.61	+0.36
105	12.81	+0.61	+0.34
106	14.17	+1.15	+0.63
107	14.51	+1.14	+0.46
109	14.69	+1.28	+0.36
110	14.18	+1.40	+0.65
108	14.15	+1.41	+0.97
112	14.23	+1.52	+0.82
113	14.15	+0.60	+0.01
115	14.10	+1.29	+0.87
155	14.42	+1.66	+0.65
173	14.55	−0.37	−0.43
201	16.08	+0.46	+0.04
222	16.00	+0.27	−0.02

of Fig. 5, dots and crosses being used as before and open circles indicating means of six values taken in order of photographic magnitude.

A full consideration of the decrease of violet-index, V.−Pg., with decreasing photographic brightness, which indicates a smaller range in violet magnitude than in photographic, must be deferred

until more definite information is at hand relative to the scale of violet magnitudes. As it now stands the violet-index for these cluster-type variables decreases as color-index increases—a result quite the contrary of the relation of the two indices shown in Table V for a number of typical invariable giant stars in this same cluster.

SUMMARY

1. The redder a Cepheid variable the greater is its intrinsic luminosity; a nearly linear relation connects absolute magnitude and color-index.

2. The general characteristics of the luminosity-period curve of Cepheid variation (Fig. 1) appear to have a reasonable explanation on the pulsation hypothesis.

3. For giant stars in at least four globular clusters the decrease of brightness with decreasing color-index parallels the same phenomenon for Cepheids. When median brightness and color are considered, the variables of a given absolute brightness are nearly four-tenths of a magnitude bluer than other giant stars (Fig. 2).

4. The composite color-curve of more than 100 cluster-type variables has been determined from two pairs of photographs of Messier 3 (Fig. 4).

5. In range of variation, form of light-curve, and phenomena of color the variables of a globular cluster apparently are exactly comparable with the average isolated cluster-type variable (Fig. 3). No evidence has been found that in different stellar systems Cepheids differ systematically either in median luminosity or in nature of variation.

6. In Messier 15 two subclasses of cluster-type variables which have distinctly dissimilar mean periods show neither a difference in median photographic magnitude nor a difference in color at the median magnitude. At maximum, stars with shortest periods may be slightly bluer.

7. Preliminary violet magnitudes of cluster-type variables indicate a smaller amplitude than in photographic light; for the giant invariable stars of clusters the violet-index, $V.-Pg.$, increases with color-index and hence with increasing photo-visual brightness.

MOUNT WILSON SOLAR OBSERVATORY
December 1917

THE INFRA-RED ARC SPECTRUM OF IRON

By H. M. RANDALL and E. F. BARKER

Captain W. de W. Abney,[1] in 1881, in mentioning his failure to photograph the infra-red arc spectrum of iron, concluded that only those metals which volatilize at low temperature possess an infra-red spectrum. In 1912 H. Lehmann[2] published the infra-red emission spectra of numerous elements obtained by the phosphorescent method, the extreme wave-lengths being about 15,000 A. Here the infra-red spectra were most successfully photographed for the easily volatilized substances, while no lines were found for iron. In the photographic region Geiger[3] has obtained results extending nearly to 1 μ. The four wave-lengths which he gives beyond 0.9 μ have, however, not been verified by the present investigators. It would appear that he had attempted to extend his measurements beyond the proper limits of his observational method. More recently K. Burns[4] has worked in the photographic infra-red region, his published values extending to 0.9 μ. In this same region Meggers and Kiess[5] have recently obtained excellent results beyond 0.9 μ, and some of their values in that region have been included in our tables. The region covered in the present investigation extends from 9000 to 30,000 A and has been found to contain some fifty measurable lines. Iron was found to be a difficult material to work with, the first attempts being very unpromising, but gradually the conditions necessary for the production of an infra-red spectrum sufficiently intense and steady for bolometric measurement were learned, so that in the region covered the infra-red iron spectrum is at present the richest in the number of its measured lines. As a large majority of these lines are weak, it is evident that the iron spectrum preserves in this region the characteristics of its photographic region. The extent and distribution of this

[1] *Proceedings of the Royal Society*, **32**, 343, 1881.

[2] *Annalen der Physik*, **39**, 53, 1912.

[3] *Ibid.*, **39**, 782, 1912.

[4] *Lick Observatory Bulletin*, **9**, 27, 1913.

[5] *Scientific Papers of the Bureau of Standards*, No. 324, June 1918.

long-wave spectrum, together with the exactness of the measurements now possible, suggest that an attempt to extend the work of Gale and Adams[1] on the pressure-shift of iron lines into the infra-red might meet with success. Should any of the lines in the neighborhood of 25,000 A belong to their *a* group and the law hold that the shift with pressure varies as the third power of the wave-length, there should be a change in the wave-length of over 4 A for an increase in pressure of 10 atmospheres, while lines of the *d* group would show a shift of more than 17 A. As it is probable that shifts of 1 A would be readily observed under conditions easily obtainable, it is evident that it is now possible to extend investigations of pressure-shifts of arc lines into the infra-red region.

As the experimental arrangement of the mirror spectrometer by which the line spectrum of the iron, produced by a grating, is passed over the slit of a linear thermopile has been described in an earlier paper,[2] it will not be discussed here. The methods of observation are also essentially the same. The grating was that used in previous work and was kindly lent us by Professor Hussey, of the Detroit Observatory. It is a flat six-inch grating with 15,000 lines per inch, ruled by Dr. Anderson, and has given very good service. The slits of collimator and thermopile were at first approximately 0.2 mm wide and covered a spectral region in the neighborhood of 1 μ of about 6 A, and at 3 μ of 3.6 A. Later the entire spectrum was examined with a slit 0.5 mm wide, and a very appreciable number of weaker lines were found and measured. No systematic differences between the values of wave-lengths measured with the slits of different width were noticed.

Through the kindness of Professor Campbell, of the department of chemistry, we obtained the American ingot iron with which the major part of the work was done. This iron is over 99.8 per cent pure, the largest single impurity being copper, which is present in the proportion of approximately 0.04 per cent. We also obtained through the courtesy of Professor Terry, of Wisconsin, a sufficient quantity of Burgess electrolytic iron to check up the results obtained with the other iron. None of the impurities, found in small

[1] *Astrophysical Journal*, **35**, 10, 1912.

[2] H. M. Randall, *Astrophysical Journal*, **34**, 1, 1911.

traces only in both irons, were found to give lines; in fact, as later experience has shown, iron less pure would probably have sufficed, as it is only when there are large quantities of volatilized metal present in the arc that the lines appear with sufficient intensity to be measured.

The iron was placed in a boring in the positive carbon, the diameter of the hole being as large as the three-quarter-inch carbon would permit. To secure greater localization of heat in the metal the carbon was occasionally nearly sawed off immediately below the boring. The carbons used showed the several infra-red K lines and also two others, whose approximate values are 11,439 A and 10,692 A. As these values do not correspond to any infra-red lines previously measured their origin is at present unknown.

The currents necessary to volatilize the metal sufficiently to produce measurable lines from the point of view of intensity and steadiness were very large, in general in excess of 60 amperes. Lines which are broadened unsymmetrically may very well have their measured values appreciably altered by the use of such currents, as was shown in earlier work, particularly with caesium,[1] although more recently[2] several barium lines capable of measurement with relatively small currents gave substantially the same values for all currents. At present there seems to be no way of avoiding large currents, and any estimation of the accuracy of determinations of wave-length must be qualified through this possibility of unsymmetrical broadening which cannot be allowed for in bolometric measurements on arc lines. Recently the inclusion of a very large inductance in the circuit has very effectively prevented the frequent extinction of the arc during observations.

The wave-lengths given in the table are in angstrom units as measured in air according to the Rowland scale, the spectrometer being calibrated with the Hg line 10,140.15 A as measured by Volks.[3] The intensities of the lines are indicated by the mean of the galvanometer deflections in millimeters of the separate determinations, two or more in number, when the 0.5 mm slit was used.

[1] H. M. Randall, *Astrophysical Journal*, **34**, 12, 1911.

[2] *Ibid.*, **42**, 200, 1915.

[3] Inaugural Dissertation, Tübingen, 1914.

These numbers given in the first column of the table are at best but a very rough indication of the relative intensities of the lines, as the deflections for any one line vary between wide limits, depending upon the state of the arc, which is always very unsteady. The column headed "Maximum Variation from Mean" will give a good idea of the reproducibility of results by the methods here used, as the values are those obtained independently by two observers working at different times, the apparatus having been dismounted and otherwise used in the meantime. In general, unless otherwise stated, the values given are considered correct to within 1 or 2 A. This estimate has been verified whenever more accurate methods have furnished standards for comparison. In the present work six lines between 0.8 μ and 1 μ, measured two or more times, show a mean variation from values obtained photographically by Meggers and Kiess of 0.9 A, the maximum single difference being -1.9 A. This is the region of the spectrum where the bolometric method is least accurate. The smaller dispersion of the grating here, together with the intensity of the general radiation in the neighborhood of 1 μ, produces a strong background of rapidly varying intensity, so that the location of lines superimposed upon it becomes very difficult. For the region between 0.8 μ and 1 μ the photographic method is the more sensitive, yielding more lines; the lines so measured should be more accurate than can be obtained by our method. Beyond 1 μ, however, the bolometric method apparently becomes increasingly the more sensitive, and accordingly our values in and beyond this region become increasingly the more reliable.

A number of the lines marked with asterisks have been measured but once, two years ago this summer. They were not found a year later when an attempt was made to measure them. While the measurements, when made, were so normal in all respects that we have great confidence in the lines, still the fact that they were not found again places them somewhat in doubt. The two strongest of the lines in this region, 25,987 A and 26,229 A, were found and remeasured last year, which strengthens the view that conditions at the first measurement were particularly favorable to the formation of a spectrum, and that for some reason it was not possible to reproduce those conditions.

In a spectrum so rich in lines as that of iron it will naturally occur that a number of the infra-red lines will coincide, within the limits of accuracy obtainable in these measurements, with the higher orders of shorter lines. When the shorter lines are weak

Int.	Wave-Length, Rowland Scale	No. of Determinations	Maximum Variation from Mean	Remarks	Int.	Wave-Length, Rowland Scale	No. of Determinations	Maximum Variation from Mean	Remarks
50...	9001.1 A	3	1.1 A	(a)	15...	14710.7 A	2	0.2 A	
40...	9090.3	2	0.8	(b)	10...	14744.2	2	0.5	
20...	9210.4	3	2.3	(c)	20...	14828.2	3	0.9	
20...	9257.1	3	2.0	(d)	20...	15054.2	3	0.8	
20...	9407.8	2	0.6	(e)	35...	15212.5	2	0.5	
15...	9740.0	3	1.4		70...	15295.7	4	0.9	
15...	10063.3	2	1.7	(f)	30...	15396.4	3	0.6	(j)
30...	10144.3	4	2.7		25...	15624.8	2	0.5	
20...	10216.0	3	2.1		40...	15771.2	2	0.6	
20...	11608.0	3	1.0		25...	15815.1	3	0.6	
25...	11640.8	2	0.1		25...	15820.8	2	0.5	
50...	11884.2	4	0.8		15...	16165.9	2	0.1	
75...	11974.7	3	0.9		15...	16317.2	2	0.5	
25...	12033.5	2	0.8		10...	16397.2*	1	.....	
45...	13564.1	2	0.9		15...	16494.6*	1	.....	
50...	13899.4	2	1.4	(g)	10...	16608.0*	1	.....	
10...	13978.5	2	0.1		10...	18856.2*	1	.....	
15...	14124.4	2	0.6		5...	25341.5*	1	.....	(k)
40...	14237.1	4	2.1	(h)	15...	25661.5*	1	.....	
40...	14287.9	4	1.6		25...	25987.4	2	0.3	
100...	14401.8	3	0.4		20...	26229.4	2	1.1	
20...	14440.4	3	2.7	(i)	5...	26487.3*	1	.....	
75...	14513.3	3	0.5		5...	26727.4*	1	.....	
35...	14558.3	4	1.8						

EXPLANATION OF REMARKS

(a) Meggers and Kiess value reduced to Rowland scale 8999.8 A.
(b) Meggers and Kiess 9089.1 A, mean of two near lines.
(c) Possible error ±3 A, Meggers and Kiess 9210.41.
(d) Possible error ±3 A, Meggers and Kiess 9259.0, mean of two near lines.
(e) Meggers and Kiess 9407.9, mean of two near lines. Meggers and Kiess 9739.0.
(f) (The foregoing means are weighted means, each line being weighted according to its estimated intensity.)
(g) Possible error ±3 A.
(h) Possible error ±3 A.
(i) Possible error ±3 A.
(j) Absorption by water too complete to be 2d order of K7699.4 (10).
(k) Possibly 4th order 6336.

their higher orders do not produce effects which are measurable radiometrically. With the strong lines absorbing screens have been used when possible to eliminate effects of higher order. In other instances the complete absorption of the observed lines by varying thicknesses of water and glass have shown them to be first-order lines of long wave-length. While some of the results in the foregoing table appear to be second orders of strong lines, it is thought, nevertheless, that in each case the effect measured is that of a superposed first-order line.

We have been very materially assisted in part of this work by Mr. Jean Cooley, whose aid was made possible through a grant by the American Academy of Science, to which we wish to acknowledge our indebtedness.

PHYSICAL LABORATORY, UNIVERSITY OF MICHIGAN
November 19, 1918

DISCUSSION OF SOME EVIDENCE ON THE ORIGIN OF RADIATION IN THE TUBE-RESISTANCE FURNACE[1]

By ARTHUR S. KING

In two recent papers[2] which give his very interesting observations with the tube-resistance furnace, Dr. Hemsalech has reached some conclusions based on evidence which is not in agreement with experimental results obtained by the writer. In the interest of a proper correlation of all available data, so that we may the sooner see what conclusions may be safely drawn, a brief account of these points of difference will be given.

Dr. Hemsalech, in observing the iron spectrum produced in a carbon-resistance tube at atmospheric pressure, did not find certain lines, notably the group near λ 4900 which is strong in the arc, until his furnace reached a temperature of about 2500° C. At this temperature he considers that the strong ionization known to take place within the tube, together with the potential difference of a few volts at its extremities, give a conduction of electricity through the vapor equivalent to a low-tension arc, and that lines of this type require such an electrical condition for their production in the furnace.

The effect of the ionized state within the tube on the radiation of the inclosed vapor is a matter which needs full investigation; but sufficient data on the electrical side are not yet available to justify the conclusion that the inclosed vapor carries a considerable part of the current, as compared with the highly conducting graphite tube, under the conditions which I have found to give spectra favorable for examination. In a former contribution[3] I reported some observations in which I repeated the experiments of Harker and Kaye[4] on the ionization current between exploring electrodes and then measured the resistance between insulated electrodes

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 162.

[2] *Philosophical Magazine* (6), **36**, 209, 281, 1918.

[3] *Mt. Wilson Contr.*, No. 73; *Astrophysical Journal*, **38**, 315, 1913.

[4] *Proceedings of the Royal Society*, **86A**, 379, 1912.

placed within the tube as compared with that of the tube itself, titanium vapor at 2600° C. being present. The results showed the resistance of the vapor to be relatively high.

Aside from the question as to how nearly the furnace at high temperature approaches a low-tension arc, the high-temperature iron lines referred to by Dr. Hemsalech have been obtained by me at temperatures much below those at which he considers that the electrical conductivity of the vapor becomes important. In my paper[1] on the furnace spectrum of iron all of the lines of the λ 4900 group are recorded as appearing with fair intensity at temperatures between 2100° and 2300°, while the two strongest were perceptible at a temperature between 1800° and 1900°. Since the publication of that paper I have occasionally photographed the iron spectrum under the more favorable conditions of improved furnace construction and the use of the 15-ft. concave grating spectrograph, the first order of which gives very bright spectra with a dispersion of 1 mm = 3.7 A. The group at λ 4900 proved more sensitive than the former results indicated, the two strongest lines, λ 4921 and λ 4958, being visible at 1650° with an exposure of 110 min., while the entire group, including the weaker components of the doublets, was well developed at 2000° with an exposure of 15 min. In fact the later experiments have shown that the classification which I have adopted does not require temperatures which Dr. Hemsalech regards as giving a low-tension arc. Iron lines of Classes I, II, and III may be classified according to their behavior at 1700° and 2000°, while 2350°, in conjunction with the arc intensities, serves to place the lines of Classes IV and V. This latter temperature was used as the high-temperature stage in a study of the ultra-violet portion of the iron spectrum now being completed. Higher temperatures increase the width of reversals and may bring out a very few extra lines, but they soon give difficulty on account of the stronger continuous ground, the emission of which finally balances the emission of most of the metallic lines, while the more reversible ones appear in absorption.

As the furnace of Dr. Hemsalech was operated at atmospheric pressure, which might affect the vaporization point of iron, I have

[1] *Mt. Wilson Contr.*, No. 66; *Astrophysical Journal*, 37, 239, 1913.

made a series of tests with air present, but the differences between Dr. Hemsalech's observations and mine are not to be ascribed to this feature. I obtained all of the lines of the λ 4900 group at atmospheric pressure, the temperature not rising above 1850°. An interesting effect, however, was a much increased chemical action with air present. Iron, when fused in the furnace, forms a carbide in vacuum, which sticks to the tube but does not penetrate deeply. With air present this action was much stronger. The iron ate into the tube and, when the latter burned thin through long use, dropped through the wall in several places. The tube was used in air without protection other than being in the steel chamber, the window-holder of which was removed. When operated first in vacuum and then with air present the change to atmospheric pressure caused a temperature increase of from 50° to 100° with the same impressed voltage, though the thinning of the tube gave a lower average current. The iron spectrum was very bright, but the most notable difference relative to the vacuum spectrum was a high intensity of the more reversible lines. The cyanogen (nitrogen?) bands were strong at 1850°.

Obviously it must be assumed that there is no large discrepancy between the temperature measurements of Dr. Hemsalech and the writer. The Wanner type of pyrometer was used in both cases, and with ordinary care this instrument, when properly adjusted with the standard lamp, and the current through the pyrometer lamp kept constant by means of a milammeter, gives very consistent readings. The extreme upper and lower temperatures measured by us were nearly the same, my photographs showing, like his, that a few iron lines are emitted at as low a temperature as 1500° C., the formation of the carbide evidently lowering the melting-point of iron.

Dr. Hemsalech in his latest paper[1] describes an experiment in which he avoids exposing the vapor to a potential difference by constructing a chamber resting on a graphite plate, the latter carrying the heating current. Judging from the drawing, the maximum temperature given by the hot plate was applied along only about one-seventh of the periphery of the four-sided chamber. The

[1] *Op. cit.*, p. 290.

fusion of both iron and copper in this inclosure failed to show a spectrum for either, and Dr. Hemsalech concludes from this that their line spectra are not to be excited by purely thermal means. Granting, however, that a potential difference was thus avoided, it would seem that if the temperature were high enough (pyrometer readings are not given) and the means of observation sufficient a large group of iron lines which are subject to thermo-chemical excitation should have appeared. This is the stimulus which Dr. Hemsalech believes produces the spectrum shown by the tube furnace up to 2500°, and there was full opportunity for the formation of iron carbide and for chemical action resulting from the presence of oxygen.

I must further call attention to two investigations in which furnaces, which seem to differ in no essential respect from this "hot plate" furnace, produced line spectra. The first case was when the writer[1] vaporized substances within a bored-out carbon placed horizontally and heated at its middle by an arc formed between the side of this carbon and a vertical electrode beneath. With this crude furnace, some twenty-eight lines of iron and three of copper were photographed. I may say in passing that the lines from the various elements studied in this furnace have corresponded fully with their low-temperature spectra when produced by the tube-resistance furnace at present in use.

The second furnace of this type was constructed by Hale, Adams, and Gale[2] in the course of their investigation of sun-spot spectra. A powerful arc passed between two horizontal carbons and heated the upper side of a carbon tube containing the substance to be vaporized. The temperature inside the tube was probably below 2000°, as titanium could not be melted, but a fairly rich iron spectrum consisting of the low-temperature lines was photographed in the green-yellow region. In both of these arc-heated furnaces a potential difference in the iron vapor is avoided.

A third point in the last paper[3] by Dr. Hemsalech on which I wish to present additional data is the failure of his tube-resistance

[1] *Astrophysical Journal*, 21, 236, 1905.

[2] *Mt. Wilson Contr.*, No. 11; *Astrophysical Journal*, 24, 185, 1906.

[3] *Op. cit.*, p. 288.

furnace to show the spectra of copper, silver, and zinc. He was unable to obtain any lines of these elements even at high temperature and concludes that in addition to showing no spectroscopic reaction at moderate temperatures their vapors are so poorly conducting that they do not respond to the potential gradient when more highly heated.

As to the appearance of copper lines in the furnace, I must again refer to my observations with the tube heated by an external arc. To obtain further data on the question raised by Dr. Hemsalech I have used copper and silver in the tube-resistance furnace and have photographed some of the stronger lines of each element, both in vacuum and at atmospheric pressure. The temperatures ranged from 2000° to 2150° and the spectrum was examined from λ 3600 to λ 5800. With silver, λλ 3682, 4055, 5209, 5466 appeared distinctly and with copper, not only λλ 5106, 5700, 5782, observed previously with the external-arc furnace, but also λ 5153 and λ 5218 were now photographed. Some strong arc lines in this region failed to appear in the furnace at the moderate temperature used, but these are mainly of diffuse structure, a type which in general requires higher temperature. The period of strong emission is brief, the line λ 5106 of copper narrowing during a ten-minute exposure from a width of over an angstrom to a sharp maximum. This is readily explained by the behavior of the copper and silver, which, instead of sticking to the carbon and remaining in the hot portion, condense near the cool ends of the tube. This could be avoided by a spraying apparatus, giving a continuous supply. Zinc was not tried with this furnace, but in previous experiments I have found it to give the same trouble, forming filmy slag across the opening of the tube.

Summarizing these experiments, it is seen that for the high-temperature lines of iron, for the production of the iron spectrum without a potential gradient, and for the spectra of copper and silver in the tube furnace, some feature of Dr. Hemsalech's experiments has prevented the observation of spectrum lines which can nevertheless be produced under conditions which I believe invalidate the conclusions which he draws from his results. I make no plea for the existence of a purely thermal radiation, which I have

long maintained is not to be proved by means of the tube furnace; still a clear disproof of the possibility of producing spectra by this means is yet to be presented. Dr. Hemsalech's work has done much to show the importance of possible chemical actions, and I believe this feature of the furnace radiation deserves to be taken into account at every point. But whatever processes of this nature may take place within the tube in any given experiment, they are controlled by the temperature, and according to present evidence it appears legitimate to employ the electric current to produce this temperature.

MOUNT WILSON SOLAR OBSERVATORY
November 19, 1918

THE INFRA-RED ARC SPECTRA OF COBALT, NICKEL, MANGANESE, AND CHROMIUM

By H. M. RANDALL and E. F. BARKER

Measurements in the infra-red region of the spectrum have yielded such fruitful results in developing the series relations of numerous elements that the major part of the work in this field has been done for this express purpose. There remain, however, the same general reasons for mapping out the spectra of all elements beyond the photographic region on the side of long wave-lengths as exist for the numerous investigations within that region. As it seemed probable that the technique developed during the measurement of the infra-red spectrum of iron[1] would serve equally well for the allied metals, cobalt, nickel, manganese, and chromium, it was decided to continue the work with these elements. The experimental arrangement remained the same, as did also the experimental methods. With the exception of manganese, which volatilized readily and gave a comparatively steady arc which yielded the strongest lines of any of the metals of this group, the metals were very similar to iron in their action in the arc. Nickel and cobalt produced possibly an even more uncertain arc than iron. While it would not be easy to say wherein the differences lay, it was nevertheless the experience of both observers that a certain amount of facility in using each substance in the arc was necessary before an arc of an intensity and steadiness sufficient for observation would result.

The materials used were the ordinary c. p. metals of commerce. This degree of purity seems at present sufficient, as no lines due to any of the impurities likely to be found in the samples used were actually found. In fact a large majority of the lines appeared sufficiently intense for measurement only when a fairly large quantity of material was in the arc and there was obviously excessive volatilization, the arc burning very noisily. The currents employed were again large, being in general between 60 and 80 amperes.

[1] Randall and Barker, "Infra-Red Arc Spectrum of Iron," *Astrophysical Journal*, **49**, 42, 1919.

The spectrum of each material was in general twice searched, once with narrow slits corresponding to a spectral region before the thermopile of from 6 A at 1 μ to 3.6 A at 3 μ, and once with double slit-widths. With cobalt the region covered extended from 0.9 μ to 2 μ; with nickel from 0.9 μ to 3 μ; the region between 2 μ and 3 μ, however, was gone over but once. With manganese the region from 0.9 μ to 2 μ was covered twice and from 2 μ to 3 μ once; with chromium from 0.9 μ to 3 μ twice.

NICKEL

Wave-Lengths Rowland Scale	Maximum Variation from Mean	Intensity	Number of Determinations	Remarks
8967.5	0.0	100	2[a]	
9522.1	0.0	40	2	Meggers and Kiess 9520.3
10195.1	1.5	50	3	
10301.4	0.0	25	2	
10330.0	0.7	25	2	
10378.1	1.0	40	3	
10980.4	0.3	50	2	
11198.1	0.0	35	2	
11591.1	2.0	30	3	Possible error $\pm$3 A°
13553.7	0.2	20	2	
13722.6	0.5	50	2	
13829.6	1.5	30	3	
13969.0	0.2	20	2	
14102.1	0.3	20	2	
14874.7	0.5	30	2	Shaded to Violet
16313.0	1.0	15	2	
16363.0	0.2	100	2	
16409.4	.....	50	1	Very doubtful; could not be verified
16495.5	.....	120	1[b]	
16868.5	0.7	15	2	
16999.6	1.4	60	5	
17986.8	0.5	20	2	
18040.6	0.8	15	2	

a Meggers and Kiess 8967.3 mean of two near lines on Rowland Scale. A number of lines shorter than 8967.5 show a mean difference of +0.6A from Meggers and Kiess values, maximum difference being 1.2 A.

b Doubtful; subsequent search showed more indications of a line. Line of equal value found once in Fe.

In a number of cases the values obtained agree within the limits of experimental error with previously measured lines of other elements. In each case, however, the strongest lines in the spectra of these other elements have not appeared, so that the lines in question have been considered new lines properly belonging to the substance under examination. In the case of manganese

measurements on a number of the lines of greatest intensity were made by our colleague, Dr. Sleator, the results being practically identical with our individual determinations.

COBALT

Wave-Lengths Rowland Scale	Maximum Variation from Mean	Intensity	Number of Determinations	Remarks
9096.5.....	1.2	10	2	M. and K. 9095.8
9357.2.....	0.4	40	2	M. and K. 9357.4
9545.8.....	0.9	100	3	M. and K. 9544.9
9598.4.....	1.4	30	2	M. and K. 9598.3
9661.3.....	.....	20	1	Found but once, doubtful
10046.6.....	3.3	30	3	Possible error ±5 A°
10128.7.....	0.1	15	2	
10170.7.....	1.9	20	3	
10359.1.....	3.9	15	3	Possible error ±5 A°
10689.7.....	0.2	40	2	
11633.5.....	0.3	20	2	
11894.5.....	0.5	10	2	
14062.0.....	1.7	40	.....	
14559.0.....	0.6	15	2	
14610.9.....	0.0	35	2	
14680.9.....	0.6	20	3	
14958.0.....	1.0	30	2	
15209.6.....	1.2	15	2	
16132.6.....	0.3	50	3	
16256.9.....	2.1	50	3	Possible error ±3 A°
16387.5.....	1.5	30	3	
16447.2.....	1.4	20	2	
16573.8.....	0.2	30	2	
17004.9.....	0.3	50	2	
17080.4.....	2.6	30	3	Possible error ±5 A°
18175.5.....	0.8	30	2	
18273.8.....	0.4	20	2	
19778.7.....	0.0	30	2	

In the case of chromium there are between 0.9 μ and 1.3 μ twenty-five measurable lines, while in the corresponding region of manganese there are but six lines, the region between 0.9 μ and 1 μ being entirely free, a very remarkable fact in view of the richness of this region for nearly all materials so far examined. In manganese in the interval from 1.3 μ to 1.7 μ are found fifteen lines, the majority of its entire number, while the corresponding region for chromium is quite empty, there being but two or three lines. From 1.7 μ onward chromium has sixteen lines, while manganese has shown no lines of measurable intensity. This alternate arrangement of the spectra of these nearly related elements

is rather striking, though probably without special significance. It is noticeable that there is in chromium, as in the case of iron, a group of lines found in the region of 2.5 μ upon which but a single measurement has been made. These measurements were in every way normal and all the lines showed complete absorption by a

MANGANESE

Wave-Lengths Rowland Scale	Maximum Variation from Mean	Intensity	Number of Determinations	Remarks
8672.3.....	1.1	80	3	
8703.1.....	0.6	100	2	
8739.9.....	0.4	80	2	
11378.4.....	0.0	15	2	
11614.4.....	2.0	40	5	
11782.8.....	2.7	60	4[a]	Possible error ±3 A?
12307.9.....	.....	.....	.....	Very doubtful; not found a second time
12900.3.....	1.4	80	4	
12976.5.....	0.9	40	5	
13294.7.....	1.1	50	3	
13318.5.....	0.6	30	5	
13416.5.....	0.5	80	2	
13500.7.....	1.3	100	3	
13626.3.....	1.8	200	6	
13685.2.....	0.2	80	2	
13864.4.....	1.6	100	5	
13997.6.....	1.6	120	5	
14970.5.....	3.8	30	4	Possible error ±3 A
15218.6.....	0.5	80	3	
15263.8.....	0.8	200	3	
15965.6.....	1.5	200	3	
17336.0.....	0.6	80	2	
17608.3.....	1.0	20	3	

a Value possibly influenced by 11771.7 K, carbon impurity.

water screen 1 cm thick. We have therefore considerable confidence in their reality but can give them here only provisionally, as we have been unable to find them a second time. It might be noticed that this group, as well as the one in iron whose members could not be measured at will, lies in the absorption band of water vapor at 2.5 μ, and that during the summer months the basement-room in which the work was carried on was comparatively damp. As by our optical arrangement the radiation from the arc passes through about 3 m of air it is quite possible that considerable energy is absorbed by the intervening vapor.

In the tables the mean of the observed values appears in the first column measured in angstrom units. The values when not

CHROMIUM

Wave-Lengths Rowland Scale	Maximum Variation from Mean	Intensity	Number of Determinations	Remarks
8947.3.....	0.3	160	2	Meggers value on Rowland scale 8947.5
8977.1.....	0.4	30	2	Meggers value on Rowland scale 8977.1
9015.4.....	2.8	300	6[a]	
9140.6.....	0.7	20	2	
9206.3.....	2.0	30	3	
9290.6.....	1.6	150	4	Meggers value 9290.8
9447.9.....	0.6	150	3	
9574.6.....	1.2	150	3	
9670.9.....	1.1	50	4	
9732.2.....	1.5	120	5	
9948.4.....	1.1	20	4	
10082.0.....	0.9	20	2	
10486.3.....	1.3	35	2	
10673.4.....	0.6	30	2	
10819.9.....	0.8	40	2	
10906.2.....	1.3	60	4	
11016.0.....	2.9	80	5	Possible error ±4 A
11157.6.....	1.4	90	6	
11311.9.....	0.7	20	2	
11337.1.....	0.6	40	2	
11392.3.....	2.6	50	5	Possible error ±3 A
11483.3.....	1.0	40	2	
11611.4.....	0.8	100	5	
13462.1.....	.....	20	1	
15680.0.....	3.7	30	4	Possible error ±3 A
15860.5.....	0.6	30	3	
18479.1.....	4.1	30	3	Possible error 5 A
18583.5.....	1.6	30	4	
18654.2.....	1.1	30	2	
18717.0.....	0.5	20	2	
25459.6*.....	.....	15	1	
25489.7.....	.....	10	1	
25560.4.....	.....	10	1	
25583.6.....	.....	20	1	
25665.4.....	.....	10	1	
25708.8.....	.....	10	1	
25784.6.....	.....	5	1	
25819.6.....	.....	10	1	
25849.7.....	.....	20	1	
25902.2.....	.....	10	1	
26232.0.....	.....	20	1	

a Broad line. Possible error 4 A. Meggers value 9016.5 (Mean).
* The following lines are to be considered doubtful until verified.

otherwise stated are supposed to be accurate within one or two angstrom units. The intensities are determined by a very rough

mean of the galvanometer deflections during measurement. They have some significance as rating the intensities of the lines of any one element, but have very little as a means of comparison of intensities between lines of various elements.

A number of the lines in the tables are multiples of strong lines of short wave-length. It is thought, however, that in each case it has been established that the higher-order line of short wave-length is superposed by a line of long wave-length of the first order. In some cases, where it has not been possible to screen out the line of higher order, it is quite probable that its presence has somewhat affected the value ascribed to the line under observation.

As an infra-red region up to 1 μ was regarded as properly within the field of photographic methods, only a superficial examination of this region was made in this work. This largely accounts for the fact that we have not measured all the strong lines which the recent work of Meggers and Kiess shows to be here. Such lines as we have measured, as the comparisons in the tables show, have a somewhat higher accuracy than we have claimed for them, taking the photographic values as standards. The mean departure of all our measured lines below 1 μ, 19 in number, including quite a number of lines shorter than 0.9 μ not contained in the tables, is 0.6 A, while the maximum variation is 1.9 A. The superiority of the photographic method in registering faint lines is made very evident by these investigations, and it may be safely concluded that, except possibly in special cases, the infra-red spectrum up to 1 μ is properly a photographic region.

Surprisingly enough, the same cannot yet be said of the region immediately beyond 1 μ, in which photographic observations have been taken with apparently as great success, in the case of Ni to 10,843 A, Co to 11,623 A, and Fe to 10,689 A. A comparison of the results obtained photographically and radiometrically shows no cases which are unquestionably in agreement, though there are in the foregoing regions twelve radiometrically determined lines and many more photographic lines.

Confidence in radiometric measurements in this region is based upon the following general considerations: The radiometric methods here employed, as well as that earlier used by Lewis,[1]

[1] *Astrophysical Journal*, 2, 1, 106, 1895.

which is similar, have given values between 0.7 μ and 1 μ, which have been substantiated by subsequent photographic results. The results under comparison are in fact an instance of such a confirmation. The same lines beyond 1 μ have been measured by different observers using different gratings and making determinations in higher orders for the strong lines with closely agreeing results, and finally with those substances for which there are series relations there have been numerous instances in which the radiometric values beyond 1 μ have so perfectly met the requirements that the confidence in their accuracy has become very great.

Since the particular lines in question have been measured under usual conditions of observation and have shown no peculiarities during observations, but have, on the other hand, been quite normal in all respects, there appears to be no reason for questioning their accuracy. In this work also we wish to express our indebtedness to the American Academy of Arts and Sciences for a grant from the Rumford fund which enabled us to obtain the services of an assistant.

PHYSICAL LABORATORY
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Minor Contributions and Notes

A STAR WITH DISAPPEARING BRIGHT LINES

In the *Journal of the Royal Astronomical Society of Canada* for November 1918 (**12**, 462), Director J. S. Plaskett, of the Dominion Astrophysical Observatory at Victoria, shows from measures of four spectrograms that the radial velocity is variable of the star Boss 5918, which is B.D. $+47°3985$ ($\alpha = 22^h53^m$, $\delta = +48°\ 9'$, mag. = 5.20, spectrum = B3). An examination of our plates and measures of this star brings out a further point of interest, which is worthy of mention, namely, that the spectrum now does not show bright hydrogen lines (or bright fringes beside the dark lines), although they were conspicuous in 1913.

Our available plates are as follows:

No.	Date	G.M.T.	Quality	Taken By
I 3446	1913 July 28	18^h52^m	Good	B, S
3457	Aug. 4	17 28	Very good	F, S
3520	Oct. 9	14 31	Ti weak	F, S
5345	1918 Aug. 5	18 22	Good	W, S
5363	Aug. 30	21 34	Good	B, S

B = Barrett; F = Frost; S = Sullivan; W = Miss Wickham.

The first two plates were measured in 1913 by myself and yielded values of -11 and -15 km per sec. as the radial velocity from the four dark hydrogen lines, ϵ, δ, γ, and β. It was noted in the measures of the first plate that there were "bright fringes on each side of Hβ." On the second plate, settings were made on the edges of the fringes. Expressed in kilometers of velocity, and in angstroms, the widths were:

Bright fringe toward violet	-239 to -111 km	2.06 A
Dark	-111 to $+16$ km	2.05 A
Bright fringe toward green	$+16$ to $+178$ km	2.61 A

In other words dark β was of the same width as the more refrangible bright fringe and somewhat narrower than the fringe toward

the green. If we should consider the dark line as superposed on a bright band 6.7 A wide, it was displaced toward the violet from the center by about 0.3 A, or about 17 km.

On the third plate the fringes at β are strong, and at γ the one on the side toward green is visible. This plate was not measured, because the comparison lines were too weak to yield a good result.

This kind of appearance at Hβ is not at all unusual for A spectra with bright lines, but it is not often that we can establish a variation in the intensity of the emission lines. Our two plates taken in August 1918, however, do not display a trace of the bright emission lines, and the entry was made on the observing card at the time by Professor Barrett, after examining the plates: "Bright lines variable?"

Mr. Plaskett makes no mention of bright lines in the notes describing this spectrum, and in response to my inquiry he states that no bright fringes are visible upon a re-examination of the Victoria spectrograms.

Professor E. C. Pickering's letter with regard to the matter reads as follows:

> An examination of our photographs of the spectrum of H.R. 8731, α 22^h8^m, δ $+48°9'$, by Miss Cannon, shows that on a photograph taken with the 8-inch Bache Telescope on November 18, 1887, and on photographs taken with the 11-inch Draper Telescope on November 5, 1904, October 27, November 14, and November 19, 1905, all the lines are dark. Hβ is a well-marked dark line with no appearance of bright edges. On a photograph taken November 3, 1913, with the 8-inch Draper Telescope, the line Hβ is not clearly seen and certainly is not present as a strong dark line.

A list of stars having bright hydrogen lines was published by Mrs. Fleming in *Harvard Annals*, **56**, Part VI, pp. 181–84. It describes the variations of the lines so far as known at the date of that publication. Miss Cannon's recent important paper on the same subject is No. 3 of Vol. **76** of the *Harvard Annals*.

EDWIN B. FROST

YERKES OBSERVATORY
January 3, 1919

Reviews

Science and Learning in France, with a Survey of Opportunities for American Students in French Universities: an Appreciation by American Scholars. By JOHN H. WIGMORE, Editor-in-Chief. Chicago: A. C. McClurg & Co., 1917. Pp. 454. Illustrations 58. Price, $1.50, cloth; $1.00, paper.

"To the Scholars of France, worthy custodians of their country's intellectual greatness, this volume, prepared in a time when France has reached the heights of moral greatness, is offered with heartfelt admiration and sympathy in the name of the Scholars of America."

There are two introductions: the first, entitled "The Mind of France," by former President Charles W. Eliot, which occupies three pages and is adorned by a photograph of Rodin's Le Penseur; the second, a charming essay of a dozen pages entitled "The Intellectual Inspiration of Paris," written in that city in September 1916 by George E. Hale.

The different branches of learning, from anthropology to zoölogy, are dealt with in successive chapters, each under the editorial care of a drafting committee of well-known American teachers. The chapters are embellished with excellent portraits of distinguished French scholars and with views of famous educational buildings of Paris and of the interiors of some of the laboratories. The aim in each section is to show the splendid intellectual past in France in that department and to indicate the present opportunities for American students who may desire to add a residence in Europe to their preparation for a specialty. Of course Paris receives the major part of the attention, but practical information is given in two appendices, of which the first is entitled "Educational Advantages for American Students in France: with a History of the Recent Changes in its University System," by Professor James Geddes, Jr., of Boston University; the second discusses "Institutions of Higher Learning,. Their Organization, Degrees, Requirements, Fees, etc.," by Professor C. Vibbert, of the University of Michigan.

A third brief appendix of twelve pages on practical suggestions to the intending graduate student is also by Professor Vibbert.

The book makes a valuable beginning in introducing the learning of France to the American student. It would, doubtless, be improved in a second edition. Its errors in the departmental chapters are probably more those of omission than of commission, although the reviewer notices both in the section on astronomy. The general approval of Americans of the purpose of the book is evidenced by the list of about 1000 "sponsors," of whom it is said, "These American scholars have expressed a cordial desire to join with the authors in making this book a national homage, offered from the Universities of America to the Universities of France."

We bespeak for the book a wide circulation and use. It should be in every college library.

F.